Water management in Ontario

Ontario
Water Resources
Commission

Water Resources
Report 1

Water Resources of the Big Otter Creek Drainage Basin

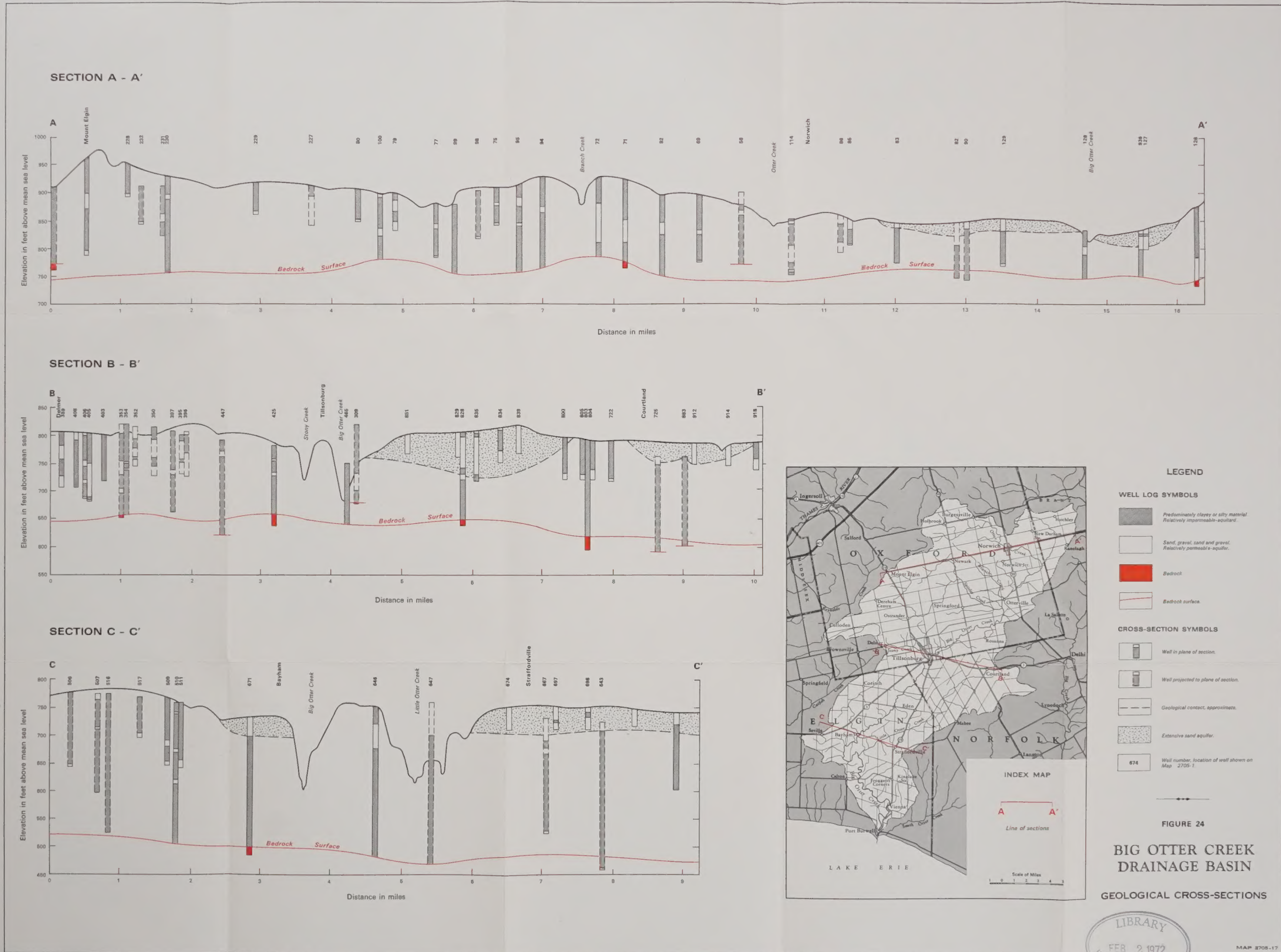
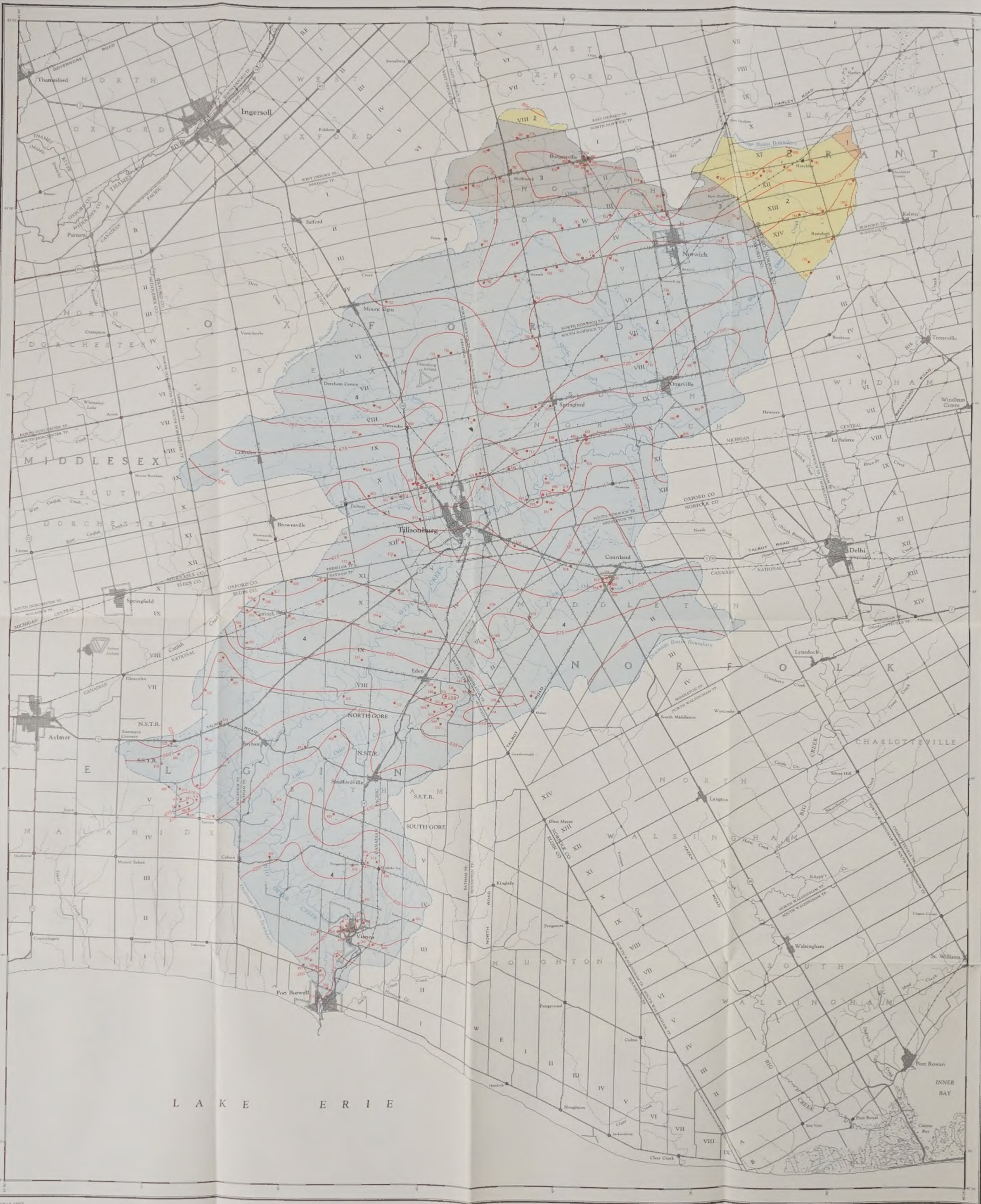


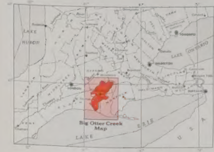
FIGURE 24

BIG OTTER CREEK DRAINAGE BASIN

GEOLOGICAL CROSS-SECTIONS

MAP 2705-17





KEY MAP

Scale 1 inch to 50 miles

LEGEND

PALÆOZOIC

DEVONIAN

4 — *DELAWARE FORMATION: brown and buff limestone, some chert.*

3 — *DETROIT RIVER GROUP: brown and buff limestone and dolomite, sandstone.*

2 — *BOIS BLANC FORMATION: limestone, dolomite and chert, sandstone.*

SILURIAN

1 — *BASS ISLAND FORMATION: cream and buff dolomite.*

SYMBOLS

Geological boundary, approximate.

625 — *Bedrock surface contour, interval 25 feet.*

Water well in bedrock.

Oil or gas well in bedrock.

Elevation of bedrock surface at well.

Town or village boundary.

Built-up area.

Centre of settlement.

Intermittent stream.

For other topographic symbols, refer to 1:50,000 National Topographic Map Series.

Note: All elevations in feet above mean sea level.

SOURCES OF INFORMATION

Bedrock topography by U. Sibul and W. Morrison, 1965/66.

Reference:

Map 2, Bedrock surface contour map, by A. Dreimanis; Catfish Creek Conservation Report, Ontario Department of Planning and Development, 1951.

Map 53-6, Elgin County and Parts of Middlesex County drift-thickness and bedrock contours, by B. V. Sanford; Geological Survey of Canada, 1953.

Map 53-31, Norfolk County drift-thickness and bedrock contours, by B. V. Sanford; Geological Survey of Canada, 1954.

Bedrock geology by U. Sibul and W. Morrison, 1965/66; on the basis of oil and gas well logs assembled by the Ontario Department of Energy and Resources Management with the co-operation of the Geological Survey of Canada.

Reference:

Map 1062A, Southwestern Ontario, by B. V. Sanford; Geological Survey of Canada, 1968.

Well information from:

Water well records on file with the Ontario Water Resources Commission.

Oil and gas well records on file with the Ontario Department of Energy and Resources Management.

Cartography by S. Impey, 1966.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

WATER RESOURCES SURVEY

BIG OTTER CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2705-2

BEDROCK GEOLOGY AND TOPOGRAPHY

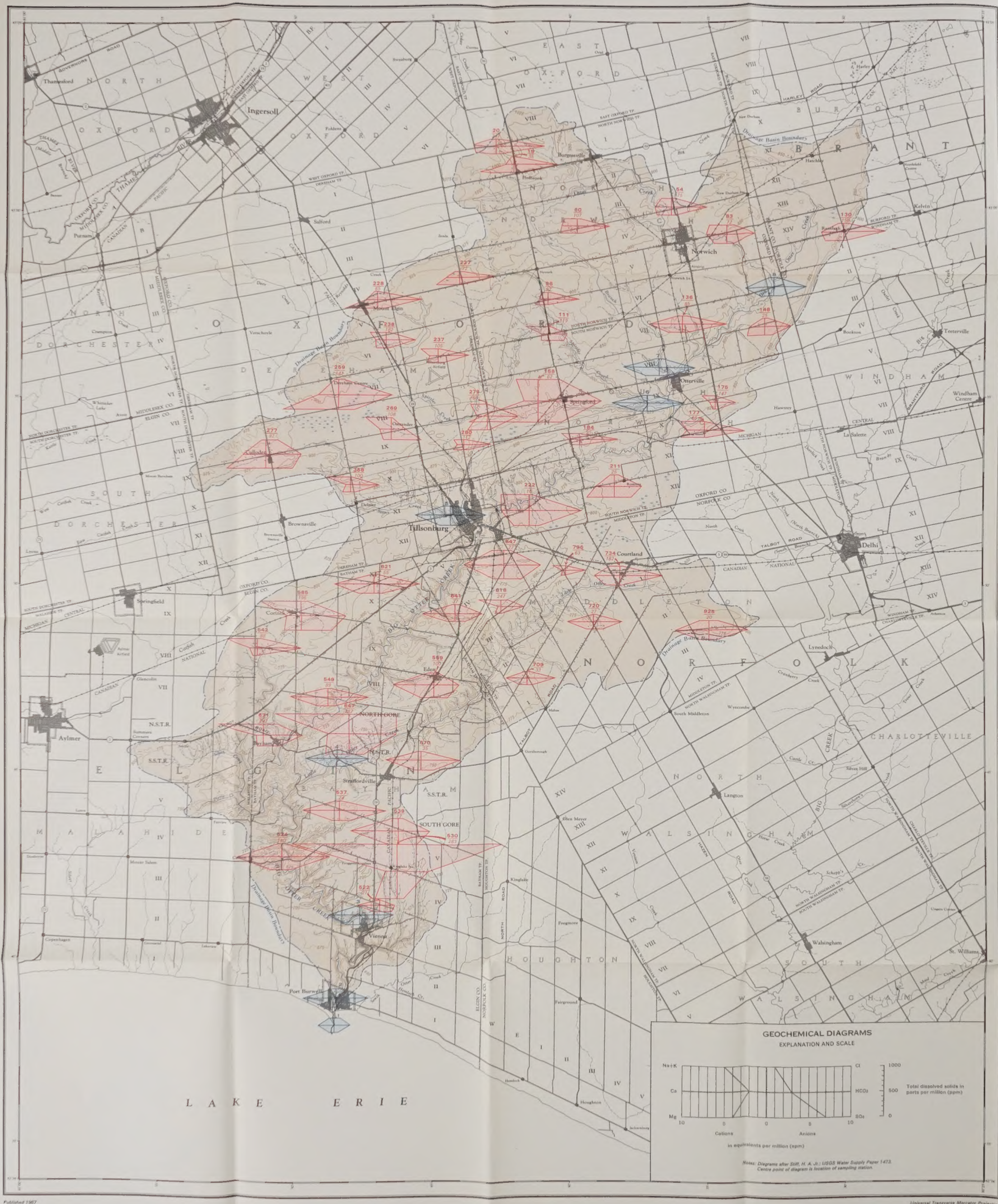
Published 1967

Universal Transverse Mercator Projection

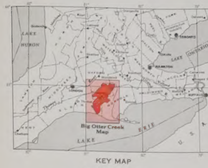
Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres



Scale 1:100,000 or 1.58 Miles to 1 Inch



KEY MAP

Scale 1 inch to 50 miles

LEGEND

- Surface-water source.
- Overburden ground-water source.
- Bedrock ground-water source.
- 4 — Surface-water sample number.
- 280 / 112 — Well number / Depth of well in feet.

SYMBOLS

- Topographic contour.
- Town or village boundary.
- Built-up area.
- Centre of settlement.
- Intermittent stream.

Note: All elevations in feet above mean sea level.

For other topographic symbols, refer to 1:50,000 National Topographic Map Series.

SOURCES OF INFORMATION

Water samples taken by U. Sibul, W. Morrison and F. Fleischer, 1965/66.
Water samples analyzed by OWRC Laboratory.

Reference:

Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey Water Supply Paper 1473, 1959.

Well information from:

Water well records on file with the Ontario Water Resources Commission. Oil and gas well records on file with the Ontario Department of Energy and Resources Management.

Cartography by S. Impey, 1967.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

WATER RESOURCES SURVEY

BIG OTTER CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2705-9

CHEMICAL QUALITY OF WATER SAMPLES

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 Inch to 50 miles

LEGEND

CENOZOIC

PLEISTOCENE

RECENT

7	*ALLUVIAL DEPOSITS: Poorly stratified silt, sand and gravel along the flood plain and flat raised terraces of Big Otter Creek and some of its main tributaries. Will yield small to moderate quantities of water to shallow wells.*
6	*SWAMP DEPOSITS: Peat, muck and some silt. Will not yield water to wells.*

WISCONSINAN

5	*BEACH DEPOSITS: Mainly sand and gravel and some fine sand marked by sorting and parallel stratification. Will yield moderate quantities of water although the deposits are limited in aerial extent.*
4	*SHALLOW-WATER LACUSTRINE AND FLUVIAL DEPOSITS: Fine-to-medium-grained, cross-bedded sand with local coarse phases at depth. The shallow-water lacustrine or deltaic deposits are found generally in plains between morainic ridges. The fluvial and spillway deposits are found on the surface and under interbedded silt and clay deposits or till. Will yield moderate to very large quantities of water to wells.*
3	*KAME AND OUTWASH DEPOSITS: Mainly stratified sand and gravel with extreme range in grain size, sorting and structure. These deposits were formed by streams flowing from glaciers. Most of the kame and outwash deposits are located along the St. Thomas moraine near Holbrook, Burgessville and Newark. These deposits are highly permeable and can yield large quantities of water, but yields are generally limited by small saturated thicknesses.*
2	*MORAINIC DEPOSITS (Undifferentiated): Three clayey silt to silty clay tills are exposed in the area. Four recessional moraines are present in the basin. All the tills are relatively impermeable, but may yield small quantities of water to dug or bored wells.*
1	*LACUSTRINE DEPOSITS: Mainly fine sand, silt and clay characterized by high degree of sorting and stratification. In many instances the deposits are thick sequences of silt, fine sand or interbedded silts and clays. Yields are usually small, because of low permeability.*

SYMBOLS

Geological boundary, approximate.

Stream terrace.

825 *Topographic contour.*

Raised shoreline.

Gravel pit.

Test-drilling site.

Town or village boundary.

Built-up area.

Centre of settlement.

Intermittent stream.

For other topographic symbols, refer to 1:50,000 National Topographic Map Series.

SOURCES OF INFORMATION

Surficial geology by U. Sibul and W. D. Morrison, 1965.

References:

The Physiography of Southern Ontario, by L.J. Chapman and D.F. Putnam, 1951.

Map 1, Pleistocene Deposits of Aylmer-Brownsville Area, Geological Map, by A. Dreimanis; Catfish Creek Conservation Report, Ontario Department of Planning and Development, 1951.

Field notes on surficial geology of Big Creek Drainage Basin by T.J. Yakutchik and U. Sibul, 1964.

Cartography by S. Impey, 1966/67.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

WATER RESOURCES SURVEY

BIG OTTER CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2705-3

SURFICIAL GEOLOGY

Published 1967

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 inch to 50 miles

LEGEND

THICKNESS OF OVERBURDEN

- *Less than 50 feet.*
- *50-100 feet.*
- *100-150 feet.*
- *150-200 feet.*
- *200-250 feet.*
- *More than 250 feet.*

SYMBOLS

- *Line of equal overburden thickness (isopach), interval 25 feet.*
- *Water well.*
- *Oil or gas well.*
- *Thickness of overburden at well in feet.*
- *Town or village boundary.*
- *Built-up area.*
- *Centre of settlement.*
- *Intermittent stream.*

For other topographic symbols, refer to 1:50,000 National Topographic Map Series.

SOURCES OF INFORMATION

Thickness of overburden by U. Sibul and W. D. Morrison, 1965/66.

References:

Map 53-6, Elgin County and Parts of Middlesex County drift-thickness and bedrock contours, by B. V. Sanford; Geological Survey of Canada, 1953.

Map 53-31, Norfolk County drift-thickness and bedrock contours, by B. V. Sanford; Geological Survey of Canada, 1954.

Well information from:

Water Well Records on file with the Ontario Water Resources Commission.

Oil and gas well records on file with the Ontario Department of Energy and Resources Management.

Cartography by S. Impey, 1966/67.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

WATER RESOURCES SURVEY

BIG OTTER CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2705-4

THICKNESS OF OVERBURDEN

KEY MAP

Scale 1 inch to 50 miles

LEGEND

Areas where wells are likely to produce less than 3 gpm (gallons per minute). Difficulties are encountered in obtaining sufficient quantities of good quality water for any purpose. Yields are limited by low permeabilities of aquifers or by thin saturated thicknesses of overburden aquifers.

Areas where wells are likely to produce 3 to 10 gpm. Supplies are generally sufficient for domestic and stock purposes. Aquifers are mainly fine to medium sand of low permeability. In the southeast region the main aquifer is surface sand, and the bedrock aquifers generally yield mineralized water.

Areas where wells are likely to produce 10 to 25 gpm. Supplies are generally plentiful for domestic and stock purposes but poor to fair as supplemental sources for irrigation. Overburden aquifers are mainly fine to coarse sand with some lenses of gravel. In the eastern region the aquifer is surface sand. In the northern region the aquifers are sand and gravel and bedrock. Yields are limited by low to moderate permeabilities and thin saturated thicknesses.

Areas where wells are likely to produce 25 to 50 gpm. Supplies may be fair to good sources for irrigation. In the central region the aquifer is shallow sand and gravel. In the extreme northern region the bedrock is the main aquifer. Yields are limited by the areal extent of the aquifers.

Areas where wells are likely to produce more than 50 gpm. Supplies are suitable for most purposes. Aquifers are sand and gravel in the central region and bedrock in the northern region.

Note: The probable yield indicated for each area represents the production of generally satisfactory quality water that can be expected from individual wells based on geology and short-term pumping tests and may not necessarily represent long-term yields.

SYMBOLS

Well ending in an overburden aquifer with probable yield consistent with availability indicated in legend.

Well ending in a bedrock aquifer with probable yield consistent with availability indicated in legend.

875 *Topographic contour.*

Town or village boundary.

Centre of settlement.

Built-up area.

Intermittent stream.

For other topographic symbols, refer to 1:50,000 National Topographic Map Series.

Note: All elevations in feet above mean sea level.

SOURCES OF INFORMATION

Availability of ground water by U. Sibul and W. D. Morrison, 1965/66.

Well information from:

Water Well Records on file with the Ontario Water Resources Commission.

Cartography by S. Impey, 1966/67.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

WATER RESOURCES SURVEY

BIG OTTER CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

2705-5

AVAILABILITY OF GROUND WATER

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 inch to 50 miles

LEGEND

- *Taking from stream or lake.*
- *Taking from dugout pond.*
- *Taking from well or well-point system.*
- *Town or village boundary.*
- *Built-up area.*
- *Centre of settlement.*
- *Intermittent stream.*
- *Topographic contour.*

For other topographic symbols, refer to 1:50,000 National Topographic Map Series.

SOURCES OF INFORMATION

Water Permit Records on file with the Ontario Water Resources Commission.

Cartography by S. Impey, 1966.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

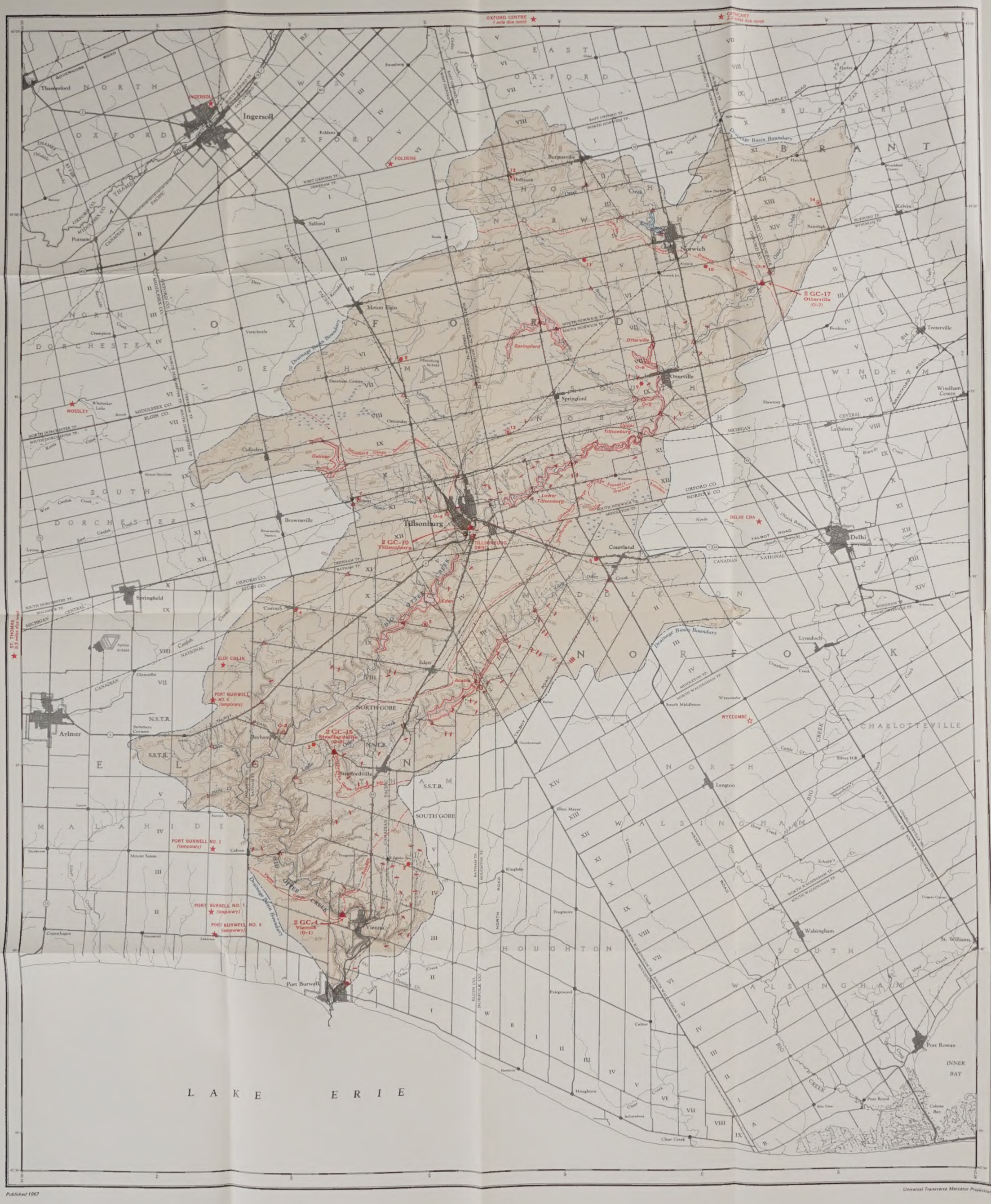
WATER RESOURCES SURVEY

BIG OTTER CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2705-6

LOCATIONS OF WATER TAKINGS AUTHORIZED BY PERMITS



Published 1967

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

KEY MAP

Scale 1 inch to 50 miles

LEGEND

- Streamflow gauging station, recording gauge.
- Streamflow station, periodic discharge measurement.
- Meteorological station, permanent.
- Meteorological station, seasonal.
- Observation well, automatic recorder.
- Observation well, manual measurement.
- Dam.
- Minor drainage boundary.
- Site for reservoir described in Otter Creek Conservation Report, Ontario Department of Planning and Development, 1957.
- Norwich Dam and Reservoir, under construction in 1965.
- Intermittent stream.
- Topographic contour.
- Town or village boundary.
- Built-up area.
- Centre of settlement.

For other topographic symbols, refer to 1:50,000 National Topographic Map Series.

SOURCES OF INFORMATION

Field survey by F. Fleischer and assistants, 1965.

Hydrometric station data from Canada Department of Northern Affairs and National Resources, Canada Department of Transport, Ontario Water Resources Commission.

Dam locations compiled by F. Fleischer with aid of aerial photographs taken in 1963 and 1964.

Cartography by S. Impey, 1966/67.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

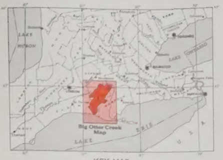
WATER RESOURCES SURVEY

BIG OTTER CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2705-7

HYDROMETRIC STATIONS, DAMS AND PROPOSED RESERVOIR SITES



KEY MAP
Scale 1 inch to 50 miles

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

LEGEND

- Open ditch or improved watercourse
- Tile
- Town or village boundary
- Built-up area
- Centre of settlement
- Intermittent stream
- Topographic contour

For other topographic symbols, refer to 1:50,000 National Topographic Map Series.

SOURCES OF INFORMATION

Information compiled by F. Fleischer with aid of aerial photographs taken in 1963 and 1964, and from records made under the following acts:
The Municipal Drainage Act
The Ditches and Watercourses Act
The Drainage Act

Cartography by S. Impey, 1966/67.

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs.

ONTARIO WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES

WATER RESOURCES SURVEY

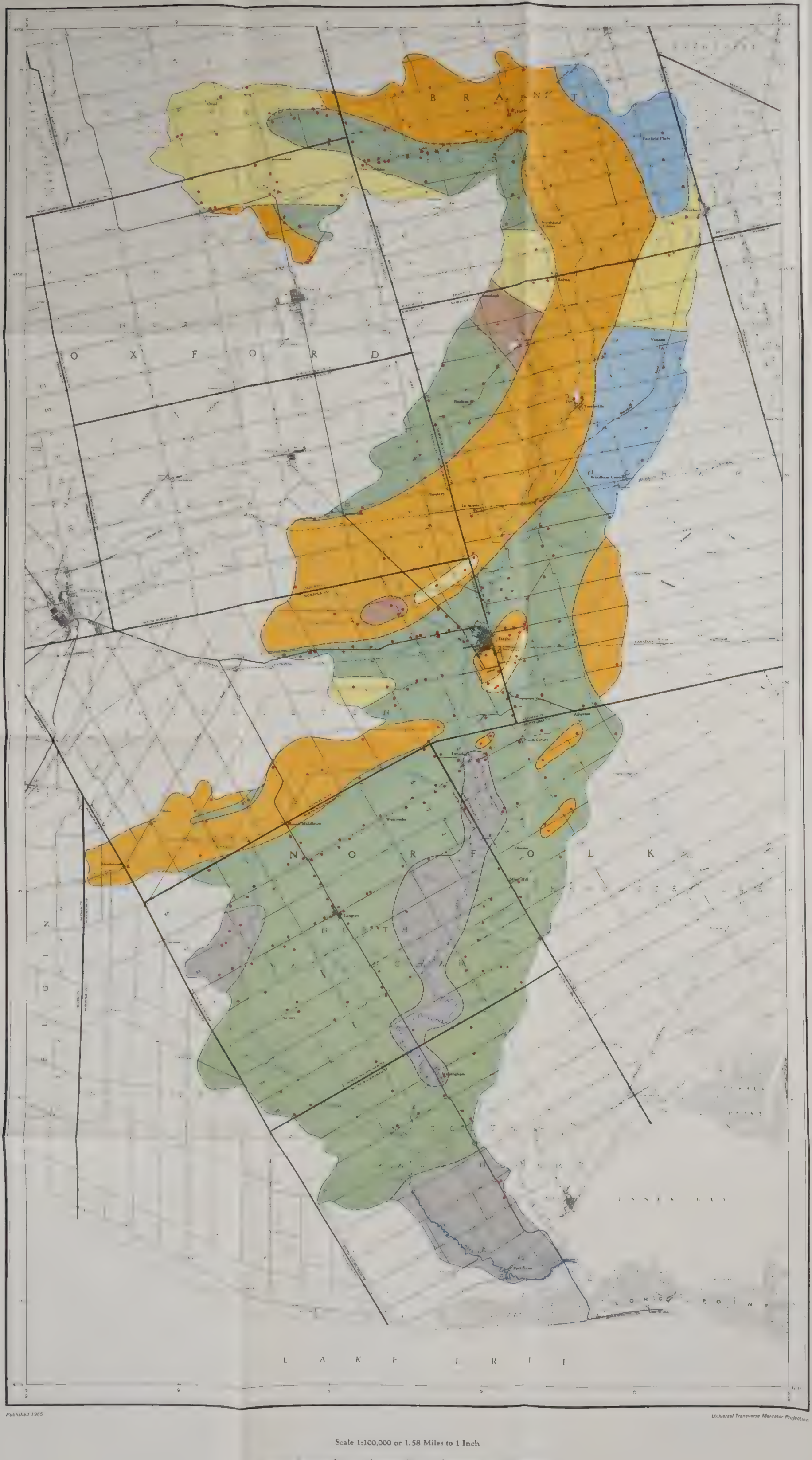
BIG OTTER CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2705-8

DRAINAGE WORKS

Government Publications



Published 1965

Universal Transverse Mercator Projection

Scale 1:100,000 or 1.58 Miles to 1 Inch

Miles

Kilometres

KEY MAP

Scale 1 inch to 50 miles

LEGEND

Areas where wells are likely to produce less than 3 gpm (gallons per minute). Difficulties are encountered in obtaining sufficient quantities of good quality water for any purpose. Yields are limited by low permeabilities of aquifers or by thin saturated thicknesses of overburden aquifers.

Areas where wells are likely to produce 3 to 10 gpm. Supplies are generally sufficient for domestic and stock purposes. Aquifers are mainly fine sand of low permeability. In the southern parts of the basin dugout ponds may be adequate for irrigation purposes. Bedrock aquifers in these areas generally yield mineralized water.

Areas where wells are likely to produce 10 to 25 gpm. Supplies are generally plentiful for domestic and stock purposes but poor to fair as supplemental sources for irrigation. Aquifers are generally fine to coarse sand. Many of the areas are favourable sources for dugout ponds. In the extreme northern end the bedrock is the main aquifer. Yields are limited by low to moderate permeabilities.

Areas where wells are likely to produce 25 to 50 gpm. Supplies may be fair to good for municipal purposes and fair as supplemental sources for irrigation. In the central regions the aquifers are mainly medium to coarse sand with occasional gravel. In the northern regions the aquifers are sand and gravel above the bedrock and the bedrock. Yields are limited by the areal extent of the aquifers.

Areas where wells are likely to yield 50 to 100 gpm. Supplies may be suitable for municipal or irrigation purposes. Aquifers are sand and gravel or bedrock. Yields are limited by areal extent of the aquifers.

Areas where wells are likely to produce more than 100 gpm. Supplies are suitable for most purposes. Aquifers are sand and gravel in the Fairfield Plain area and bedrock near Windham Centre. Aquifers have high permeabilities but the yields from the overburden may be limited in some localities by thin saturated thicknesses.

Note: The probable yield indicated for each area represents the production of generally satisfactory quality water that can be expected from individual wells based on geology and short term pumping tests and may not necessarily represent long term yields.

SYMBOLS

Well where an overburden aquifer is source of probable yield

Well where a bedrock aquifer is source of probable yield

SOURCES OF INFORMATION

Availability of groundwater by T. J. Yakutchik and U. Sibul 1965

Well information from Water Well Records on file with the Ontario Water Resources Commission

Cartography by H. A. Flotner and S. Impey 1965

Base map derived from 1:50,000 sheets of the National Topographic Series, with additional information by staff surveys, from Ontario Department of Highways maps, and from aerial photographs

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

WATER RESOURCES SURVEY

BIG CREEK DRAINAGE BASIN

SOUTHERN ONTARIO

MAP 2706-5

AVAILABILITY OF GROUND WATER

INSET B — COURTLAND
Scale 6 Inches to 1 Mile
INSET D — EDEN
INSET E — STRAFFORDVILLE
Scale 4 Inches to 1 Mile
Norwich
Tillsonburg
Delhi
Springfield

Tillsonburg
Delhi
Springfield
Aylmer
Straffordville
Port Burwell
LAKE ERIE
Town of Tillsonburg
CONCESSION X
CONCESSION XI
CONCESSION XII
INSET A – TILLSONBURG
Scale 4 Inches to 1 Mile
LEGEND
Test hole
Drilled well in overburden
Drilled well in bedrock
Abandoned drilled well or well site in overburden
Abandoned drilled well or well site in bedrock
Flowing drilled well in overburden
Flowing drilled well in bedrock
Abandoned flowing drilled well or well site in bedrock.
Bored or dug well
Well point
Abandoned well point or well-point site.
Drilled municipal well in overburden
Drilled municipal well in bedrock
Drilled irrigation well in overburden
Drilled irrigation well in bedrock
Flowing drilled irrigation well in bedrock.
Abandoned drilled irrigation well or well site in overburden.
Abandoned drilled irrigation well or well site in bedrock
Irrigation well-point system
Abandoned irrigation well-point system or site.
Drilled industrial well in overburden
Drilled industrial well in bedrock
Well number
Note: This map shows the location of wells for which water well records have been filed with the Ontario Water Resources Commission.
Cartography by S. Impey 1966
ONTARIO WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES
WATER RESOURCES SURVEY
BIG OTTER CREEK DRAINAGE BASIN
SOUTHERN ONTARIO
MAP 2105-1
LOCATIONS OF WATER WELLS
Scale 1:50,000 or 1.27 Inches to 1 Mile

Water management in Ontario

Ontario
Water Resources
Commission

Water Resources
Report 1

Water Resources of the Big Otter Creek Drainage Basin

WATER RESOURCES
REPORT 1

Water Resources of the Big Otter Creek Drainage Basin

By
U. Sibul

ONTARIO WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES

TORONTO ONTARIO

1969

PREFACE

Ever-increasing pressures placed on water resources by a growing population and a changing technology necessitate orderly development and careful management if maximum benefits are to be derived from the resource. In the Province of Ontario, the Ontario Water Resources Commission is empowered to carry out water-resources studies required to plan for resource utilization.

Drainage basin surveys are one means established by the Commission as part of its long-range program of water-resources management. In 1963 and 1964 such surveys were oriented to be acceptable as projects for financial support under the Federal-Provincial Rural Development Agreement that is administered in Ontario by the ARDA Branch of the Ontario Department of Agriculture and Food. The survey in Big Otter Creek was carried out under ARDA Project 25007.

Data for the survey were drawn mainly from material on file and from that gathered during one year's field work. Attention was focused on improvement of the hydrometric networks, quantitative and qualitative assessments of groundwater and surface-water resources, water use, and the hydrologic budget as a key to resource development.

K. Symons.

K. E. Symons, Director,
Division of Water Resources.

Toronto,
February 1, 1969.

Water Resources of the
Big Otter Creek Drainage Basin

ERRATA SHEET

Page	Particulars	Correction needed
[ap 2705-1		Wells 353 and 354 should be: "abandoned drilled well or well site in bedrock"
[ap 2705-1		Well 226 should be: "irrigation well-point system"
[ap 2705-1		Well 530 should be: "drilled well in bedrock"
[ap 2705-1		Well 524 should be: "drilled well in overburden"
	headings in Table 1	Headings should read: "Normal Temperature (°F)" and "Normal Precipitation (inches)"
6	explanation under Plate 4	Should have semicolon (;) after ". . . moraine"
pposite 34 and on vii	re: Figure 11	Below figure, should read: "(1949-1962, 1964, 1965)"
57	equation of SAR	Should read: "SAR $= \dfrac{Na^{+}}{\sqrt{\dfrac{Ca^{++} + Mg^{++}}{2}}}$ "
58	re: Figure 21	Well 671 should be a "bedrock ground-water sample"

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(in pocket)

Plates

Tables

WATER RESOURCES
OF THE
BIG OTTER CREEK BASIN

ABSTRACT

The water-resources survey undertaken in the Big Otter Creek drainage basin in 1965 is part of a program of regional water-resources investigations conducted by the Ontario Water Resources Commission to plan for the development and management of the water resources of the province. The Big Otter Creek basin was chosen because of the increasing demands for water for irrigation of tobacco.

Field investigations were made of surficial geology, surface-water flows, and farm water use. Observation wells were installed and water samples were collected for chemical analysis.

The report presents an evaluation of ground- and surface-water resources in terms of occurrence, distribution, quantity and quality of water in relation to the existing uses in the basin. A simplified hydrologic budget is presented.

The only area in the basin where there is difficulty in obtaining sufficient ground-water supplies of acceptable quality is in the southern portion. Ground-water supplies in the rest of the basin are derived from overburden sand and gravel aquifers and water-bearing zones in the upper portions of the bedrock. Most of these waters are of good quality for domestic, stock and irrigation purposes.

Surface-water supplies are utilized mostly for irrigation. At most locations these supplies are adequate in quantity and of acceptable quality for irrigation. Since no large bodies of surface water occur in the watershed, stream runoff, composed to a large degree of ground-water discharge, is the main source of surface-water supply. The withdrawal of water during short periods of irrigation in July and August has a marked effect on the streamflow of Big Otter Creek. Lake Erie, to the south of the basin, is a potential source of supply.

In the 1964-65 water year, total precipitation for the basin was calculated to be 30.81 inches — 6.85 inches below the normal at Delhi. Stream runoff was calculated to be 15.10 inches. The difference, assumed to be due mainly to evapotranspiration, was 15.71 inches. This amount was 7.66 inches below the potential evapotranspiration as calculated by the Thornthwaite method.

The water resources were found to be generally adequate for the present uses in the basin; however, local shortages and quality problems exist and require special development and management practices.

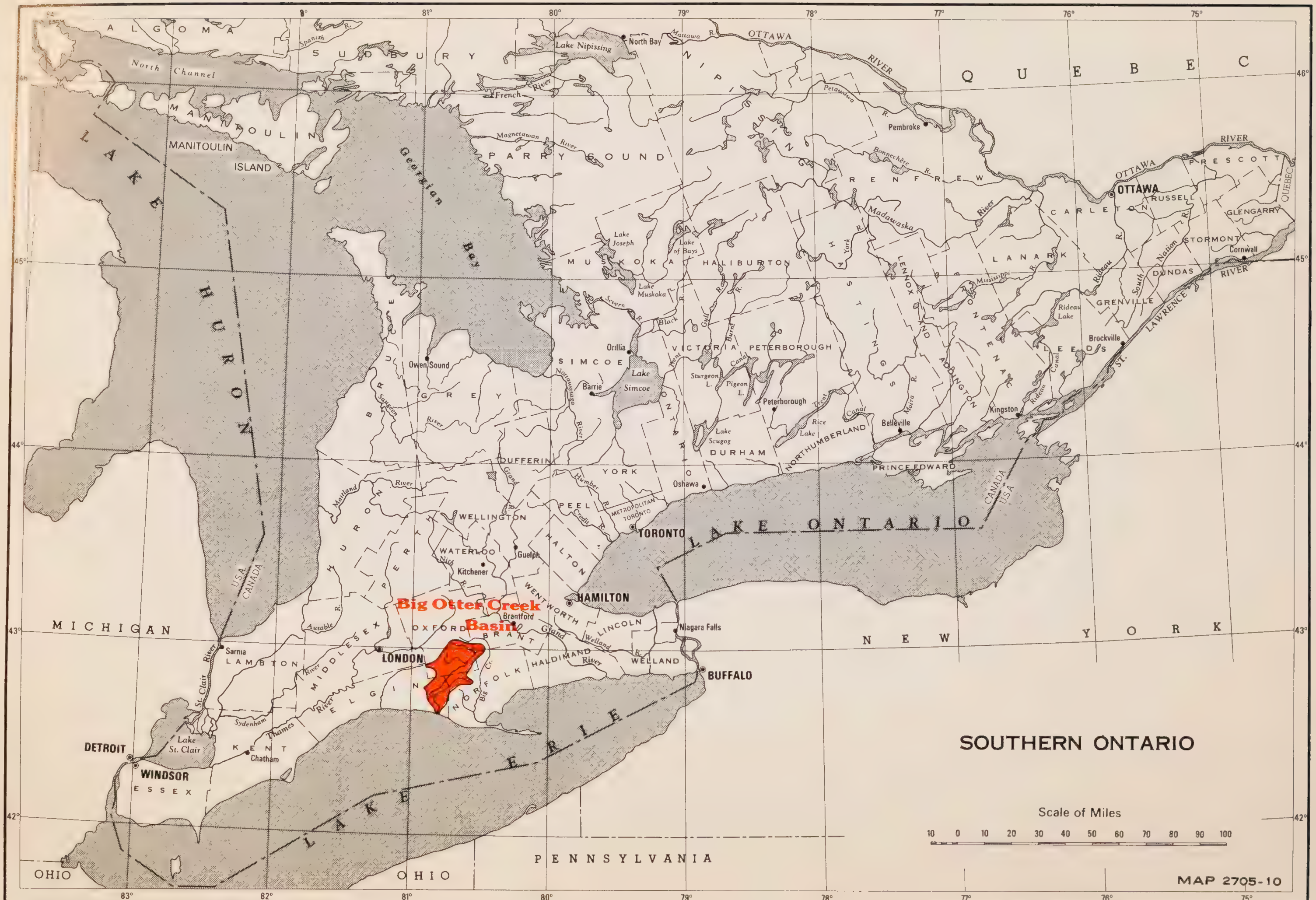

FIGURE 1 —Location of Big Otter Creek basin in Southern Ontario.

INTRODUCTION

Purpose and Scope of the Investigation

Drainage basin surveys are undertaken as part of a program of regional water-resources studies initiated by the Ontario Water Resources Commission to plan for the development and management of the water resources of the province. Such a water-resources survey was undertaken in the Big Otter Creek drainage basin because of the increasing demands for water for the irrigation of tobacco crops which have resulted in conflicts for available supplies. The study was initiated in 1965 and was supported financially under the Federal-Provincial Rural Development Agreement.

This report presents an evaluation of water resources in terms of the quantity, quality and occurrence of water in relation to present and future uses. The objective of the report is to set out basic resource information for the guidance of individuals, groups and agencies in the development of the water resources to meet independent and collective needs.

Field investigations were made of geology, surface-water flows, ground-water levels, water quality and water uses. The work included a basin wide survey of wells and other sources of water. Test drilling was conducted to provide observation wells and to supplement existing geologic information. Consistent with the data available, a general hydrologic budget was prepared.

Location of the Area

The Otter Creek drainage basin in southwestern Ontario is located between longitudes 80°29′ and 80°57′ W and latitudes 42°38′ and 43°03′ N, and drains into Lake Erie at Port Burwell (Figure 1). Big Otter Creek and its tributaries drain an area of 275 square miles which comprises parts of the following counties and townships:

County	Township
Brant	Burford
Elgin	Bayham Malahide
Middlesex	South Dorchester
Norfolk	Houghton Middleton Windham
Oxford	Dereham East Oxford North Norwich South Norwich

The largest concentration of population is in the Town of Tillsonburg near the center of the drainage area.

Previous Investigations

The Ontario Water Resources Commission has published reports on the water resources of Elgin County (1959), Norfolk County (1963) and Brant County (1964). Ground-water surveys have been conducted for the communities of Courtland, Port Burwell, Straffordville, Tillsonburg, and Vienna, and reports are on file at the offices of the Commission in Toronto.

A report of a comprehensive investigation of the drainage basin was published by the Conservation Branch of the Ontario Department of Planning and Development (1957) as a guide for the Otter Creek Conservation Authority. The report deals with five topics: history, land use, forestry, water, and wildlife and recreation. The report also covers the adjacent basin of South Otter Creek which is not considered in the present report. A summary of the 1957 Otter Creek Conservation Report, with up-to-date revisions, was published by the Ontario Department of Lands and Forests (1962).

An informative study of a specific area in the basin was presented to the Otter Creek Conservation Authority by Vance, Needles, Bergendoff and Smith Ltd., consulting Engineers (1964). This report describes the drainage area, hydrometeorology, water quality, land use, water requirements for irrigation and recreational facilities of the Little Otter Creek watershed. The report has served as a useful reference in gathering material for specific portions of the present report.

Pleistocene geology and physiography of the general area were described by Chapman and Putnam (1951).

A report by Wicklund and Richards (1961) includes a soil map of the County of Oxford as well as data on geology, climate, drainage, and soil parent materials. A description of each soil series is given, together with a discussion of its use, for agricultural purposes.

Two maps by Sanford (1953) show drift-thickness and bedrock-elevation contours in Elgin County which is partially in the Big Otter Creek drainage basin.

The streamflow records that were used in this study were published by the Canada Department of Northern Affairs and National Resources. In subsequent reorganizations, the branch publishing the data became part of the Canada Department of Energy, Mines and Resources and this department now has the responsibility of obtaining and publishing streamflow data. All meteorological data were published by the Canada Department of Transport.

In Ontario, licensed water-well contractors are required to submit well records, which contain geologic and hydrologic data, to the Ontario Water Resources Commission. The records for this basin have been used extensively in this study.

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GEOGRAPHY

Physiography

The topography of the region is directly associated with deposits of the last continental glacier that occupied the area. The valley of Big Otter Creek is the result of erosion of these deposits after the retreat of the ice sheet from the drainage basin. Two main physiographic forms predominate in the area: the morainic ridges in the north and northwest, known as the Mount Elgin Ridges, and the sand plain in the south and southeast, known as the Norfolk Sand Plain (Chapman and Putnam, 1951).

The St. Thomas, Norwich and Tillsonburg end moraines display sharp, high ridges and rolling knob-and-kettle topography which characterizes much of the western and northwestern part of the watershed.

The surficial deposits of the Norfolk Sand Plain consist of lacustrine sand and silt deposited in glacial lakes Whittlesey and Warren. The plain extends from the northeast corner to the southern end of the drainage area. The general slope of the plain is southward from an elevation of about 850 feet (above mean sea level) in the north to approximately 625 feet at Lake Erie.

The steep cliffs at Port Burwell are approximately 50 to 75 feet high and are subject to undercutting by the waters of Lake Erie. Blocks as wide as 200 to 300 feet, adjacent to the cliffs, have slumped 30 or 40 feet vertically downward.

Main drainage of the basin is through Big Otter Creek and its tributaries which have cut deep, V-shaped valleys into the central sand plain and the silt and till areas of the south.

Elevations within the basin range from 1075 feet near Holbrook on the St. Thomas moraine to 572 feet at Lake Erie.

Climate

The generally temperate climate of the region is modified by the presence of Lake Erie to the south. Putnam and Chapman (1938) have classified this part of southern Ontario as "Lake Erie Counties" and "South Slopes" climatic zones. Most of the Big Otter Creek basin lies within the Lake Erie Counties zone with only the northern regions of higher elevation belonging to the South Slopes zone. Length of the frost-free interval in the Lake Erie Counties zone varies from 135 to 160 days and the growing season, which is about 200 days per year, extends from mid-April to the first week in November. In the South Slopes zone the frost-free interval varies from 133 to 147 days and the length of the growing season is the same as in the Lake Erie Counties zone.

For general climatic characterization of the watershed, the meteorological station at Delhi is considered to provide representative data. The normal annual precipitation at this station, over 30 years of record, is 37.66 inches. The normal monthly temperature and precipitation for the Big Otter Creek drainage basin are shown in Table 1.

Table 1. **Monthly Temperature and Precipitation Normals for Big Otter Creek Basin (for 30 years of record at Delhi, Ontario)**

Month	Normal Temperature (inches)	Normal Precipitation (°F)
January	23.1	3.07
February	23.8	3.09
March	31.9	3.18
April	44.0	3.59
May	55.1	3.36
June	65.6	2.92
July	70.1	3.05
August	68.4	3.15
September	60.9	3.21
October	50.4	2.92
November	38.3	3.02
December	27.1	3.10
Normal Annual	48.1	37.66

Population

The population of the basin is about 23,000. Tillsonburg, Norwich, Port Burwell and Vienna are the only incorporated communities. Tillsonburg is incorporated as a town and in 1965 had an assessed population of 6682; Norwich, Port Burwell and Vienna are villages with assessed populations of 1666, 678 and 371 respectively (Ontario Dept. Municipal Affairs, 1966). The remaining 13,600 make up the rural population.

In general, the populations of both the urban and the rural farming areas are relatively static and future population increases are expected to be slow. The density of the rural farms throughout the basin is relatively constant with the distribution of the farms being regulated by the grid pattern of the concession roads.

Land Use

The Big Otter Creek drainage basin contains 174,918 acres of land with the following breakdown by townships:

Township	Acreage Within Basin	% of Total Basin Acreage
Bayham (1)	44,666	25.5
Dereham (2)	30,656	17.5
North Norwich	29,952	17.1
South Norwich (3)	28,288	16.2
Middleton (2)	23,744	13.6
Malahide	7,686	4.4
Burford	6,464	3.7
Windham	1,792	1.0
East Oxford	1,152	.7
South Dorchester	128	.1
Houghton	390	.2
Totals	174,918	100.0

Notes

(1) Including the Village of Vienna and part of the Village of Port Burwell.
(2) Including part of the Town of Tillsonburg.
(3) Including the Village of Norwich.

With respect to acreage, the main crops are corn, pasture, oats, hay and tobacco. To maintain soil organic content and to control erosion, rye and wheat are used mainly as rotation crops on the tobacco lands of the Norfolk Sand Plain.

Table 2 presents a detailed summary, by townships, of the use of land in the Big Otter Creek drainage basin.

The area is a major tobacco producer where harvested acreages have increased 17-fold, yield per acre has doubled, and total production of tobacco has thus increased by 34-fold since 1924. Much of this increase in yield is due to improved cropping and curing methods, use of insecticides and fertilizers, and sprinkler irrigation practices.

On the heavier soils in the basin, dairy farming is dominant. Table 3 is a tabulation of the distribution, by township, of livestock in the watershed.

In areas of poor soil drainage, such as the silt till regions of the northern half of the watershed, attempts have been made to improve drainage by tiling the fields. Municipal drains and ditches have been widely developed to improve many existing watercourses (Map 2705-8).

The Department of Lands and Forests manages many Otter Creek Conservation Authority owned woodlots and poorly-drained areas in an effort to prevent total stripping of land and to preserve and promote fish and wildlife conservation in the basin.

Table 2. **Land Use, Big Otter Creek Basin, 1965**

Township		Tobacco	Oats	Corn	Hay	Pasture	Rye	Wheat	Orchard	Barley	Swamp and Wood	Garden and Mixed Residential
Bayham	acreage	3850	1070	4280	1620	2410	1670	2380	0	80	9400	40
	% of basin total	35	9	21	14	13	26	31	0	20	61	13
Burford	acreage	300	560	980	490	870	120	190	10	20	1090	20
	% of basin total	3	5	4	4	5	2	2	2	4	7	6
Dereham	acreage	110	3500	6100	3770	5290	80	520	10	110	80	50
	% of basin total	1	29	27	33	30	1	7	3	29	—	14
E. Oxford	acreage	0	240	270	140	210	0	70	60	10	140	—
	% of basin total	0	2	1	1	1	0	1	12	4	1	—
Malahide	acreage	470	500	300	300	1070	210	300	50	20	1980	10
	% of basin total	4	4	1	1	6	3	4	10	7	13	3
Middleton	acreage	2440	420	1250	1250	1180	1530	1280	30	30	140	30
	% of basin total	22	4	6	6	7	24	17	5	8	1	10
N. Norwich	acreage	490	4300		5900	5190	510	880	350	60	2370	50
	% of basin total	4	36		26	29	8	11	68	16	15	16
S. Norwich	acreage	3020	1330		1280	1530	2100	1770	—	20	110	130
	% of basin total	27	11		11	9	33	23	—	5	1	37
Windham	acreage	400	20		60	70	200	330	—	20	170	—
	% of basin total	4	—		1	—	3	4	—	7	1	1
Total acreage in basin		11080	11920	22380	11470	17840	6440	7710	520	380	15470	340

Table 3. Livestock Distribution, Big Otter Creek Basin, 1965

Township		Milk Cows	Beef Cows	Hogs	Poultry	Horses	Sheep	Turkeys
Bayham	number	945	2568	2514	40236	253	—	—
	% of total	9.3	15.4	9.0	13.0	23.7	—	—
Dereham	number	1913	5739	13650	190395	111	46	—
	% of total	18.9	34.4	49.0	61.4	10.4	37.7	—
N. Norwich	number	4429	2797	6895	9227	86	—	84000
	% of total	43.9	16.7	24.8	3.0	8.1	—	100
S. Norwich	number	810	2403	2426	10030	284	—	—
	% of total	8.0	14.4	8.8	3.2	26.6	—	—
Middleton	number	494	1480	725	52226	181	—	—
	% of total	4.9	8.9	2.7	16.9	16.9	—	—
Malahide	number	927	927'	918	1218	72	—	—
	% of total	9.2	5.6	3.4	.4	6.7	—	—
Burford	number	370	597	485	6274	44	76	—
	% of total	3.6	3.6	1.7	2.0	4.1	62.3	—
Windham	number	4	105	63	—	24	—	—
	% of total	—	.5	.2	—	2.2	—	—
E. Oxford	number	192	72	127	235	13	—	—
	% of total	2.2	.5	.4	.1	1.3	—	—
Total number in basin		10,075	16,688	27,803	309,841	1,068	122	84,000

GEOLOGY

Introduction

In water-resources work it is important to know the composition, hydraulic properties, and subsurface distribution of earth materials. These factors are all related to the origin of the materials and hence to the geologic history. The geologic history of Big Otter Creek basin in interpreted from field examination of the geologic deposits and landforms, complemented by the reports of earlier workers, notably Chapman and Putnam (1951), Dreimanis (1951), Karrow (1963), and Sanford (1958).

The present landscape is mainly the result of deposition associated with glaciation during the late stages of the Pleistocene Epoch. Deposition and erosion by water have also left their mark. At one time during the Wisconsinan stage, ice covered all of Ontario and the Great Lakes basin. In southwestern Ontario the ice first melted and exposed the central part of the peninsula. The ice fronts then receded toward Lake Huron to the northwest and Lake Erie to the south. The debris within the ice was deposited as "ground moraine", a thin blanket of till forming an uneven surface. Where the glacier front remained temporarily stationary, the debris accumulated as a ridge or "end moraine". Meltwaters from the glacier eroded channels and deposited sand and gravel as "outwash". Extensive lakes were formed when the drainage was blocked by ice. Remnants of the shorelines of these lakes are still present at surface, and "lacustrine" deposits cover a good portion of the basin below these shorelines.

The thickness of the overburden varies from approximately 50 feet at the northern end to about 300 feet at the southern end of the basin (Map 2705-4). In general the overburden or "drift" is comprised of glacial till (a mixture of clay, silt, sand, and boulders); lacustrine silt, clay, and sand; outwash sand and gravel; and recent deposits of alluvium and organic matter. Shallow-lacustrine deposits and outwash sand cover most of the low, flat areas; glacial till predominates in the morainic ridges.

The bedrock formations beneath the drift are mostly limestones and shales. They originated as sediments in the seas which covered this region during the Silurian and Devonian Periods, some 400 million years ago. They occur as rather thick, uniform beds extending over a wide area. The nature and extent of individual formations and the sequence of formations are known from studies of outcrops and from records of deep wells.

The long interval of erosion that followed deposition of the sedimentary rocks produced an irregular upper surface modified by a drainage pattern of stream channels. The bedrock geology and the topography of the bedrock surface are both shown on Map 2705-2. There are no bedrock outcrops in Big Otter Creek basin, as the rock surface is now completely covered by glacial drift.

Bedrock Geology

Stratigraphy

Four Palaeozoic rock units are present at the bedrock surface below the overburden within the Big Otter Creek drainage basin. They are said to subcrop and are classified (Sanford, 1958) as follows:

System		Rock unit
Devonian:	—	Delaware Formation
	—	Detroit River Group
	—	Bois Blanc Formation
Silurian:	—	Bass Island Formation

The oldest sedimentary unit found to subcrop below the overburden is the Silurian Bass Island Formation. This formation consists of grey to brown- and cream-coloured, fine granular dolomite. The Bass Island Formation subcrops at the extreme northeastern corner of the basin and overlies the older Salina Formation.

In southern Ontario the Oriskany Sandstone overlies the Bass Island Formation in some localities. A few scattered drill logs report sandstone, possibly Oriskany, in the proper interval, but these occurrences are not mappable as a unit in the basin. Sandstone at the base of the overlying Bois Blanc Formation presents an additional difficulty in positive identification of the Oriskany Formation.

The Devonian Bois Blanc Formation lies disconformably on the Bass Island and is characterized by grey limestone and sandy limestone and dolomite with abundant nodular chert. This formation subcrops as a band that crosses the northern part of the basin.

The Bois Blanc Formation grades upward to brown and buff limestone and dolomite of the Detroit River Group. According to Sanford (1962), a biohermal development (Formosa Reef) is present in the lower part of the Detroit River Group and represents the only known biohermal reef in rocks of Devonian age in southwestern Ontario.

Just outside of the northwestern edge of the basin, the Detroit River Group is overlain by the Columbus Formation. However, the Columbus Formation is not present in the basin and consequently the younger Delaware Formation disconformably overlies the Detroit River Group.

The Delaware Formation ". . . consists of buff, clastic limestone grading upward into brown, finely crystalline limestone, with interbedded black shale." (Sanford, 1962, p.80). Most of the basin is underlain by this formation. The top of the formation is limestone except at a few localities in the south where it includes black shales. Because the Delaware Formation is overlain by shale or shaly limestone of the Hamilton Formation, the exact classification of the black shales reported in some holes is difficult. However, the literature on the area classifies the shales as Delaware, which is suitable for this report.

Topography of the Bedrock Surface

Elevation contours on the bedrock surface have been drawn utilizing data from oil and gas wells and from water wells that were drilled to the rock and recorded with the Ontario Water Resources Commission (Map 2705-2). The

bedrock elevation ranges from about 825 feet above mean sea level in the northern part of the basin to approximately 370 feet near Port Burwell where the Lake Erie water level stands at an elevation of 572 feet. The general slope of the top of the bedrock surface is toward the south at an average of 16 feet per mile.

Pleistocene Geology

The main land forms related to glaciation in the basin are: end moraines, a ground moraine, the Norfolk Sand Plain, kettles, spillways, and abandoned shorelines. The Pleistocene deposits of the basin include four till units, sand and gravel of glacial streams, beach gravels and stratified sands and silts of glacial lakes. The surficial deposits are shown on Map 2705-3.

Morainic Deposits

The building of the end moraines is the result of the retreating Erie-Ontario ice lobe. The tills that form the St. Thomas and Norwich moraines are the same as those identified by Dreimanis (1951) in the Catfish Creek basin to the west as the "lower till" of Port Stanley age. These tills are composed of silty clay to clayey silt with local gradation to sandy silt.

The St. Thomas moraine forms the northwestern boundary of the basin. It extends to the southwest from Mount Elgin as a high, well developed ridge and to the northwest as a gently rolling feature. A prominent break in the moraine is found in Dereham Township, concession VII, lots 19 and 20 (Map 2705-3). This signifies an overflow channel which drained meltwater ponded between the ice and the moraine.

Southeast of the St. Thomas moraine, parallel to it, and separated from it by a sand and till plain, is the Norwich moraine. This moraine extends from just north of Norwich to Delmer as a relatively subdued and gently rolling ridge. It is not well defined from Norwich to Ostrander. Northeast of Norwich only traces of the silt till, which elsewhere caps the moraine, can be found.

The Tillsonburg end moraine is a well developed ridge that marks the northeastern boundary of the basin, curves west and crosses the basin just north of Tillsonburg, then curves south and forms part of the western boundary of the basin. It has a cap of silt till which is locally stony and overlies grey lacustrine silt. In one section along Big Otter Creek, the silt till of the moraine has a distinct boulder pavement on the bottom and this is underlain by fine sands and silts.

A gentle ridge crosses the lower part of the drainage basin from northeast to southwest and forms the divide between Big Otter Creek and its tributary, Little Otter Creek. Near Eden it has the topography characteristic of an end moraine but becomes subdued to the northeast and also to the southwest, where it is buried by a cover of sand. The ridge is parallel to the Tillsonburg moraine and separated from it by a band of surficial lacustrine silt and sand. The moraine is composed of silt till which in places is very sandy immediately above the sand which underlies it. Some evidence in the Big Creek basin to the east indicates that this ridge may be an extension of the Paris moraine (Yakutchik *et al.*, in preparation). Although there is no conclusive evidence for such a correlation in Big Otter Creek basin, the feature was labelled as "Paris moraine" on Map 2705-3.

A rolling plain, underlain by silt till, lies between the northeastern extent of the St. Thomas and Norwich moraines. In places the Norwich moraine is so subdued that there is very little in the way of topographic expression to distinguish between it and the till plain to the north. The surface of the plain has been reworked by lake waters and consequently the material is difficult to identify as till. Lacustrine silts are noted at several localities, usually on the higher knobs and overlying the till.

The oldest till exposed in the Big Otter Creek basin is in a gravel pit in North Norwich Township, concession IV, lot 1-2 (Plate 1). It is a compact, stony, sand till and contains many large boulders. This may be the Catfish Creek till originally identified by Dreimanis (1951) in the Catfish Creek basin to the west. According to Karrow (1963) the Catfish Creek till is the oldest deposit definitely related to the last advance of ice into the area. In this outcrop the till is overlain by about 5 feet of bedded silt and sand and then by the lower Port Stanley silt till that forms the core of the St. Thomas and Norwich moraines to the west.

Younger Port Stanley till, typically a silt to clay till with moderate amounts of stone and pebbles, forms the Tillsonburg moraine and is thought to have been formed during a readvance of the ice in the area (Dreimanis, 1951). At present,

Plate 1 – Catfish Creek Till (?) overlying poorly sorted outwash gravels; North Norwich Twp., Con. IV, Lot 2.

the "Paris moraine" is considered to have been formed by a fluctuating ice front which was retreating from the Tillsonburg moraine. If there is a justified correlation of this moraine with the Paris moraine in the Big Creek basin, the till cap would be of Wentworth age (Karrow, 1963).

Shallow-Water Lacustrine and Fluvial Deposits

The southeastern half of the basin, along the lowlands adjacent to Big Otter Creek and Little Otter Creek, is part of the extensive Norfolk Sand Plain, a major physiographic feature of this part of Ontario (Chapman and Putnam, 1951). The surface of the plain is typically flat with minor undulations where the blanket of lake sediments does not completely mask the former surface. The end moraines to the northwest were the uplands that formed the western shore of ancient lakes Arkona, Whittlesey, and Warren. The abandoned shorelines are marked by wave-cut scarps (Plate 2), beach sand and gravel, and sand dunes. The position of a shoreline is important because it indicates the highest elevation at which sediments of a particular lake can occur. Parts of the Tillsonburg moraine projected as islands in Lake Whittlesey, and extensive lake deposits are confined to elevations below these shorelines.

Plate 2 – Abandoned Lake Warren shoreline, looking northeast; ¼ mile due East of Straffordville.

The most extensive lake sediments are silts and fine- to medium-grained sands which in places are up to 80 feet thick. Many of the deeper cuts along Big Otter Creek, especially south of Tillsonburg, expose 40 to 50 feet of sand. The sand was probably deposited as deltaic material at the mouths of streams flowing into glacial lakes Whittlesey and Warren. In places the sand is covered by three to four feet of silty clay till, suggesting that the present valley of Big Otter Creek was a lowland, flooded by sediment-laden waters, before the last advance of the glacier into the area. Sand this thick is not exposed elsewhere in the basin.

Lacustrine Deposits

Clays are not areally extensive at surface and usually occur in layers alternating with silt. These layered silts and clays are found in some places at the top of lacustrine sequences, and also just below the surficial sands of the Norfolk Sand Plain.

A complex of lacustrine clays and silts, seen in many cuts near Vienna, is called the "Vienna Complex". This complex lies on the lower Port Stanley till and grades into a heterogeneous mixture of clay and silt that locally contains pebbles and cobbles. Inclusions of clay and silt "balls" are common.

In many horizons the complex displays faint bedding and resembles water-laid till. The whole sequence displays crude stratification by gradations in grain size, pebble content, and number of silt and clay inclusions but there are no distinct horizons of either clean silt or clay. The top of the complex grades into a homogeneous silt which is in turn overlain by bedded sand. Except for the faint bedding, the bottom of the sequence appears to be a silty clay till. An excellent section of the Vienna Complex is exposed in the bluffs of Lake Erie, about ¼ mile east of the mouth of Big Otter Creek. From the top of the ground surface downward the section is as follows:

Depth (in feet)	Material
0 - 3	Fine to medium yellow sand.
3 - 7	Bedded, light silts, fine sand and silty clay; few small beds of clay are present.
7 - 32	Contorted silty clay and silt at the top. The top of the section contains no pebbles or stones but about 20 feet down, pebbles are noted and the stratification becomes indistinct. At a depth of 32 feet the material is massive silty clay.
32 - 42	Silty clay containing both silt and clay inclusions; the intensity of faint contorted bedding varies; bottom of the section grades into a massive silty clay containing pebbles and large stones; very faint stratification is still visible.

From about 10 feet down the material was probably deposited in a lake close to an oscillating ice front.

Kame and Outwash Deposits

The meltwaters flowing from glaciers usually carry large loads of coarse sediments. These sediments may be deposited on, or against the ice, or they may be carried some distance from the ice front before being deposited in the spillway channel of the meltwater stream. The ice-contact deposits in the area are kames which are isolated hills of sand and gravel remaining after the retreat of the glacier. Kames can also be recognized by the slumped bedding that is the result of melting of the adjacent ice. There are numerous kames closely associated with the St. Thomas moraine. They consist of distinctly bedded and well-sorted sand and gravel (Plate 3).

Plate 3 – Ice-contact deposit associated with the St. Thomas moraine; Dereham Twp., Con. II, Lot 46.

Most of the outwash material associated with the St. Thomas moraine is located along the northwestern, or front, side of the moraine (Plate 4), and hence is not found in Big Otter Creek basin. Outwash material also occurs northwest of and in front of the Tillsonburg moraine but only a remnant of the original deposit is still present. This relationship between outwash deposits and moraines is a significant feature of ground-water occurrence in southwestern Ontario that should be considered in ground-water exploration.

Plate 4 – Outwash material in front (northwest) of the St. Thomas moraine, Dereham Twp., Con. VI, Lot 27.

Kettles are closed, undrained depressions formed by land subsidence over buried, melting ice. Numerous kettles are found in close association with kame deposits. Where kettles are deep enough to intersect the water-table, they contain permanent ponds or swamps. An excellent example of a kettle is found at the northwestern flank of the St. Thomas moraine just north of Mount Elgin.

History of the Pleistocene Deposits

From abundant field evidence it is known that continental glaciers covered this region of North America and then retreated at least four times during the Pleistocene Epoch. In this part of Ontario only the deposits of the last, or Wisconsinan stage, have been positively identified.

In the Big Otter Creek basin, the earliest geologic event, visible from surface deposits, was the forming of the St. Thomas and Norwich end moraines by a retreating ice front. The moraines are composed of what is believed to be Lower Port Stanley till. Subsequent withdrawal of the ice from the basin was followed by a period of inundation of parts of the moraines and the area to the southeast. Silt and fine sand were deposited on parts of the Norwich moraine and parts of the moraine were bevelled.

On the re-advance of the ice, lake sediments were overridden and incorporated into the ice. At the western limit of this ice advance, the Tillsonburg moraine was formed of what is believed to be upper Port Stanley till. The "Paris moraine" may have been formed during a pause in the retreat of the Port Stanley ice front or during a subsequent re-advance that deposited Wentworth till in the Paris moraine at Delhi.

Meltwater from the retreating ice fronts eroded sizeable spillway channels between the moraines in the north and deposited deltas in ponded water or glacial lakes between the moraines in the south. Fluctuations in lake levels are attested to by the presence of raised shorelines at a variety of elevations (Map 2705-3). A beachline at Seville (elevation 775 feet) may represent the level of one of the earlier lake stages, Lake Arkona (Dreimanis, 1951). A significant shoreline along the Tillsonburg moraine probably represents the highest lake stage, Lake Whittlesey (elevation 830 feet).

The tops of this moraine protruded as islands in Lake Whittlesey and most of the surficial sand and silt in the basin was deposited in this lake below the elevation of the shorelines. Changes in the drainage of the Great Lakes basin resulted in a lowering of lake levels through several stages during which time the formation of Lake Warren, and subsequently the present Lake Erie, took place. Since then the area has been subjected to aeolian and stream erosion and the Big Otter Creek drainage network developed its present pattern.

Recent Geology

Alluvial Deposits

Alluvial material is found along most of the larger river courses and abandoned alluvial terraces of the watershed. In many cases the alluvium is a lag sediment remaining when finer particles have been washed from the parent material. In the northern regions of the basin, the alluvium consists of sand, gravel, and large stones and boulders. Towards the south, the alluvium consists of finer sediments of gravel, sand and silt.

Big Otter Creek exhibits well-defined alluvial terraces and terrace scarps. It is the only stream in the area that has raised terraces. South of Bayham, three distinct terraces have been noted. The highest terrace on either side of the river forms a pair whereas the intermediate and lower (modern) terraces are paired at some localities and unpaired at others. The highest (and oldest)

terrace displays a good scarp and indicates that the flood plain of the stream at that time was nearly a mile wide near the mouth of Big Otter Creek. Most of the lowest flood plain is completely covered with recent alluvial material; many of the higher terraces are not.

Swamp Deposits

The bogs and swamps in the area are poorly drained kettles, abandoned stream channels, and low depressions where water is found in a thin saturated cover of fine sand over less permeable silt, clay or till. In areas along Big Otter Creek north of Otterville, swamps are located behind natural levees on the present flood plain of the stream.

Most swamps in the basin are covered with dense forest vegetation and probably contain peat, muck and silt in varying proportions. The peat deposit in the low swampy area between Dereham Centre and Culloden is possibly of economic importance and is presently being developed.

HYDROLOGY

Introduction

A major part of a water-resources survey is the study of the distribution of water and of its chemical and physical properties in a particular environment. This represents essentially the science of hydrology which classically includes this study and that of the circulation of water in the earth's atmosphere, on the surface of the land and in the crust of the earth. The broad view of the water movement process is known as the "hydrologic cycle". This cycle serves as a guide for examining the quantitative distribution and quality of water in an area.

Hydrologic Cycle

The hydrologic cycle encompasses water circulation in three components of the total earth system: the atmosphere, which is made up of gases; the hydrosphere, which constitutes the bodies of water covering the earth's surface; and the lithosphere, which is the unconsolidated material and solid rock making up the earth's crust.

On a global scale, the principal processes are:

(1) evaporation from the oceans and evapotranspiration from land areas;

(2) transportation of the water vapor by atmospheric circulation;

(3) condensation and precipitation of the water vapor; and

(4) return of precipitation on the land to the ocean as streamflow.

On a smaller scale, other processes such as infiltration and ground-water percolation are also important.

During precipitation, some evaporation takes place before the moisture reaches the surface of the earth and some water is intercepted by foliage. Of the remaining precipitation, some infiltrates into the ground, some evaporates, and the remaining forms over-land flow to streams. Part of the water that infiltrates may be retained near the surface as soil moisture or move laterally as interflow; the rest percolates down to the water-table to increase ground-water storage. From the saturated zone, ground water can be released through springs and seeps, through underwater discharge to lakes and streams, through transpiration of vegetation, and through direct flow to the oceans. Some ground water may percolate deep into the ground and be effectively removed from the cycle for a long interval of time.

Most of the precipitation that does not infiltrate into the soil becomes storm runoff and flows directly into streams, ponds and lakes. Except for closed drainage systems, surface waters tend to flow towards the oceans with evaporation taking place throughout the movement in this direction. Intercepted precipitation will evaporate directly from the surface of the foliage.

Ground Water

Source, Movement and Discharge

In almost all cases, in a basin such as that of Big Otter Creek, all surface water, soil moisture and some ground water have their origin as precipitation within the basin.

It is possible that in the subsurface some water percolates across the boundaries of the basin but there is no evidence that this is significant here.

The water-table marks the top of the zone of saturation, and water in this zone is called "ground water". Movement of ground water is governed by the total fluid potential, a function of total head and gravity, the movement being from higher to lower values. The water level in a well is commonly a measure of the fluid potential and so has a special significance in hydrology. A map with contours showing the configuration of the water-table indicates the gradient and direction of ground-water flow in Big Otter Creek basin (Figure 2).

The water-table tends to conform to the topography so that the general lateral movement of ground water is from topographically high to low areas. Consequently, throughout most of the basin, movement of ground water is influenced by the deeper channels of Big Otter Creek and its main tributaries. Ground-water discharge to streams accounts for the sustained streamflow during dry periods when direct storm runoff, which is likely drained from the basin within about 7 days after a rainstorm, does not exist. Monthly values of base flows for the 1964-65 water year are shown in Table 6. A simplified base-flow hydrograph was constructed by drawing a smooth curve joining the points of low flow (Figures 7a and 7b).

Ground water is also discharged out of the basin by evapotranspiration, by extraction through wells for consumptive use, and by subsurface underflow out of the basin.

The process of evapotranspiration involves the loss of water through evaporation from all water, soil, snow, ice, vegetative and other surfaces as well as transpiration by plants. Direct measurement of actual evapotranspiration is difficult. Potential evapotranspiration may be calculated by means of empirical formulae (Viehmeyer, 1964).

The withdrawal of ground water through wells and irrigation ponds represents a major means of ground-water discharge. The evaluation of the net loss of water through irrigation is difficult because undoubtedly some of the irrigation water extracted from ground-water storage returns to the saturated zone.

Subsurface underflow out of the basin could occur through artesian aquifers that extend out of the basin under the drainage boundary. The amount of underflow out of the basin was not determined, but was considered to be equal to the underflow into the watershed. Underflow out of the basin through the saturated alluvium of Big Otter Creek is considered negligible.

Water-Level Fluctuations

Changes in ground-water storage are reflected by fluctuations of ground-water levels. Although changes in barometric pressure and air temperature produce water-table and piezometric-surface fluctuations, (Meyboom, 1967), it is the fluctuations brought about by differences in recharge and discharge rates to and from the saturated zone which indicate changes in ground-water storage.

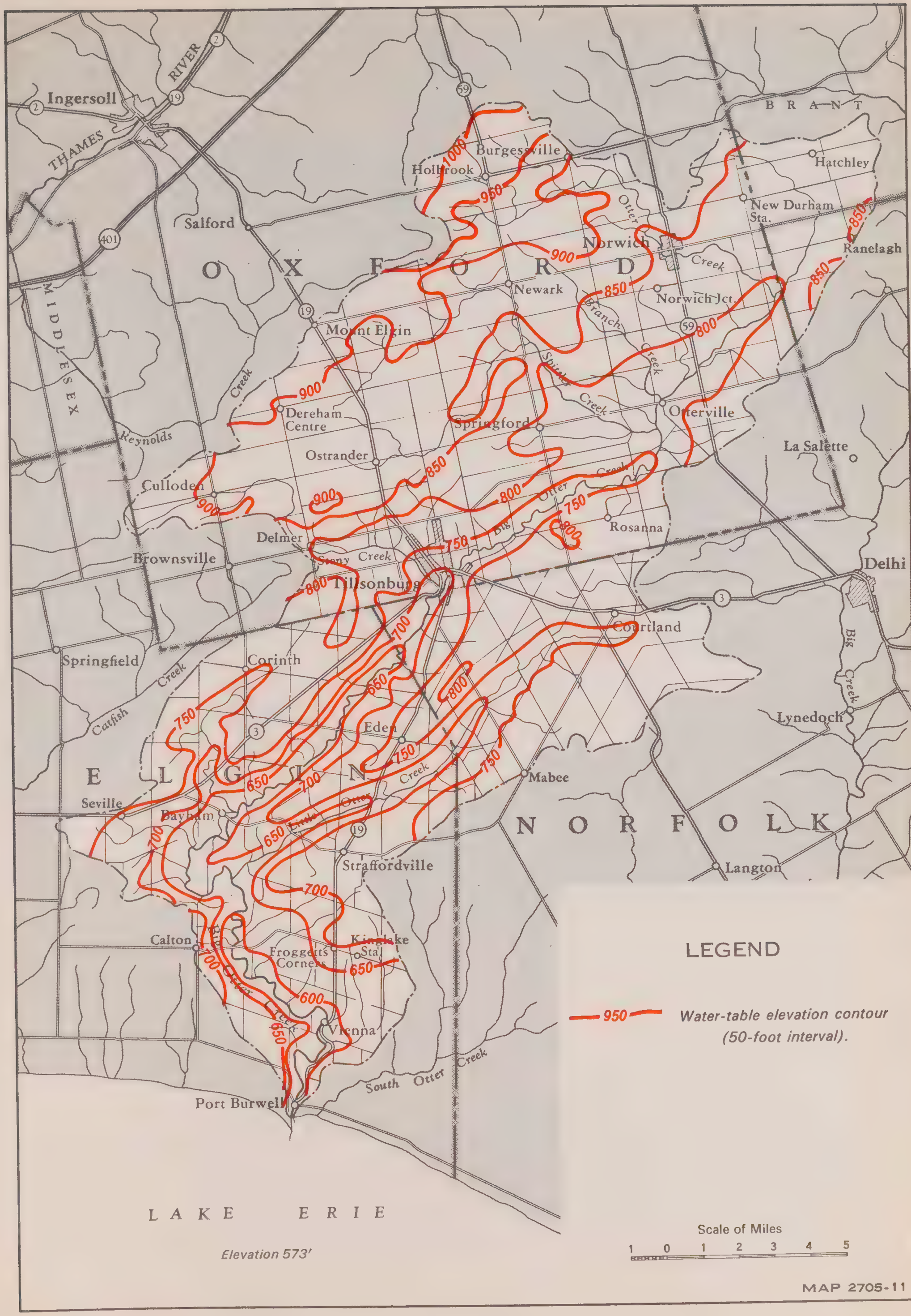


FIGURE 2—Generalized configuration of the water table, Big Otter Creek basin.

Average daily water-table levels in three selected observation wells (equipped with automatic recorders) are shown in Figure 3. Each well ends in a different type of material; well 12 in till, well 7 in silt and well 5 in fine-to-medium-grained sand.

The difference in the hydrographs of the three wells is marked. Observation well 12 indicates the sharpest response after rainfall, whereas the response in well 5 is gradual and subdued. This illustrates that in the less permeable material water-table changes are sharper and greater. Average monthly water-table conditions in these three wells are shown in Figure 4.

Piezometer nests at observation-well sites 13 and 14 (Map 2705-7) were installed to determine the direction of vertical flow components at these locations, and thus learn something of the ground-water flow system. Figure 5 is a record of the monthly water-level fluctuations recorded at different depths.

Throughout the observation period, ground-water recharge conditions at site 13 have prevailed. An average downward gradient of 0.47 feet per foot of depth is indicated between the depths of 28- and 122-feet in the two 7-inch observation wells. Because both wells end in permeable materials, the response time may be assumed to be negligible (Gilliland, 1967).

The vertical differences of ground-water potentials at site 14 are not as clear. The potentials at the 59- and 79-foot depths are close to each other, as well as being very close to the water-table. The frequency and magnitude of the daily water-table fluctuations are much greater than the water-level fluctuations in the two deeper piezometers. Because the water-table elevation is consistently the lowest of the three water levels, ground-water discharge in the area is indicated. Most of the time an upward component of flow also exists from the top of the bedrock to the overburden.

There seems to be a relatively good hydraulic connection throughout the overburden at both sides even though interbedded clays and silts occur in each vertical section.

The hydrographs of these piezometers and observation wells show annual cyclic fluctuations, a feature typical of this hydrologic environment. The maximum recharge to ground water in the basin is during the non-growing season when transpiration is at a minimum and when large quantities of water are available from precipitation and snowmelt.

Surface Water

Big Otter Creek

Physiographic Description

Big Otter Creek rises in the relatively flat and swampy northeastern corner of the drainage basin. The initial southwestern course of the stream is controlled by the Norwich and Tillsonburg morainic ridges. Just south of Otterville it passes through a gap in the Tillsonburg moraine and hence flows southwest towards the Town of Tillsonburg. Two miles below Bayham it bends around the southern-most extremity of the "Paris moraine" and flows southeast to discharge into Lake Erie at Port Burwell.

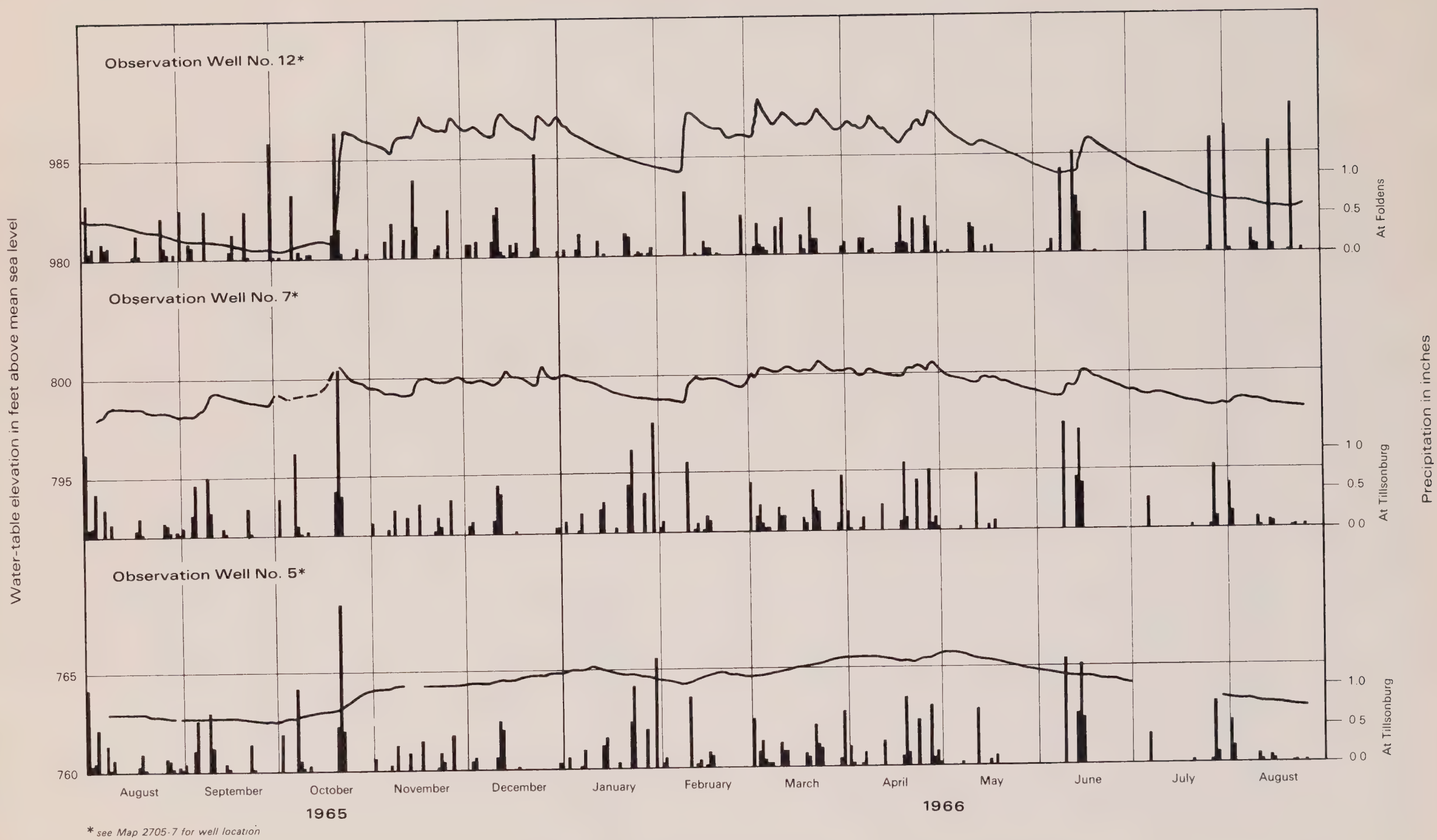
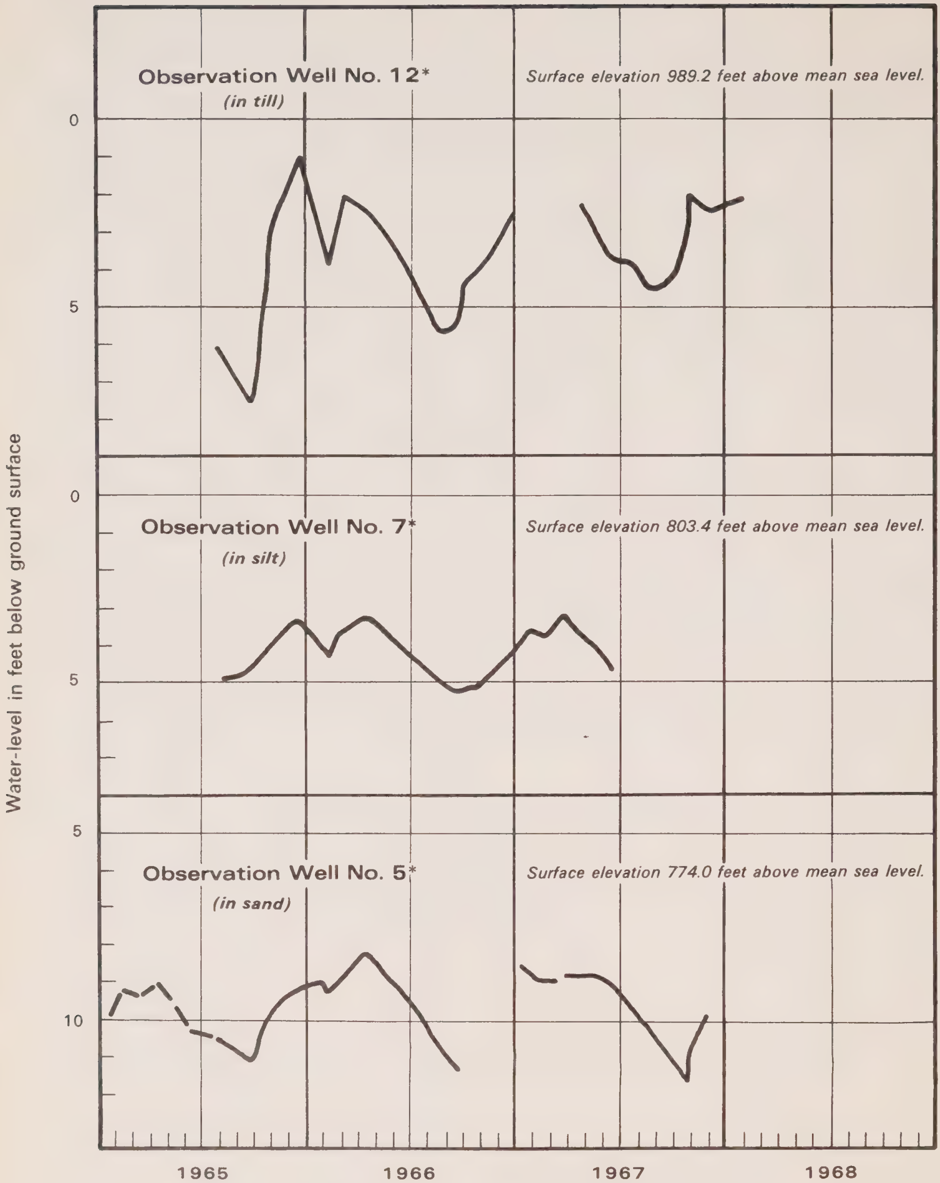
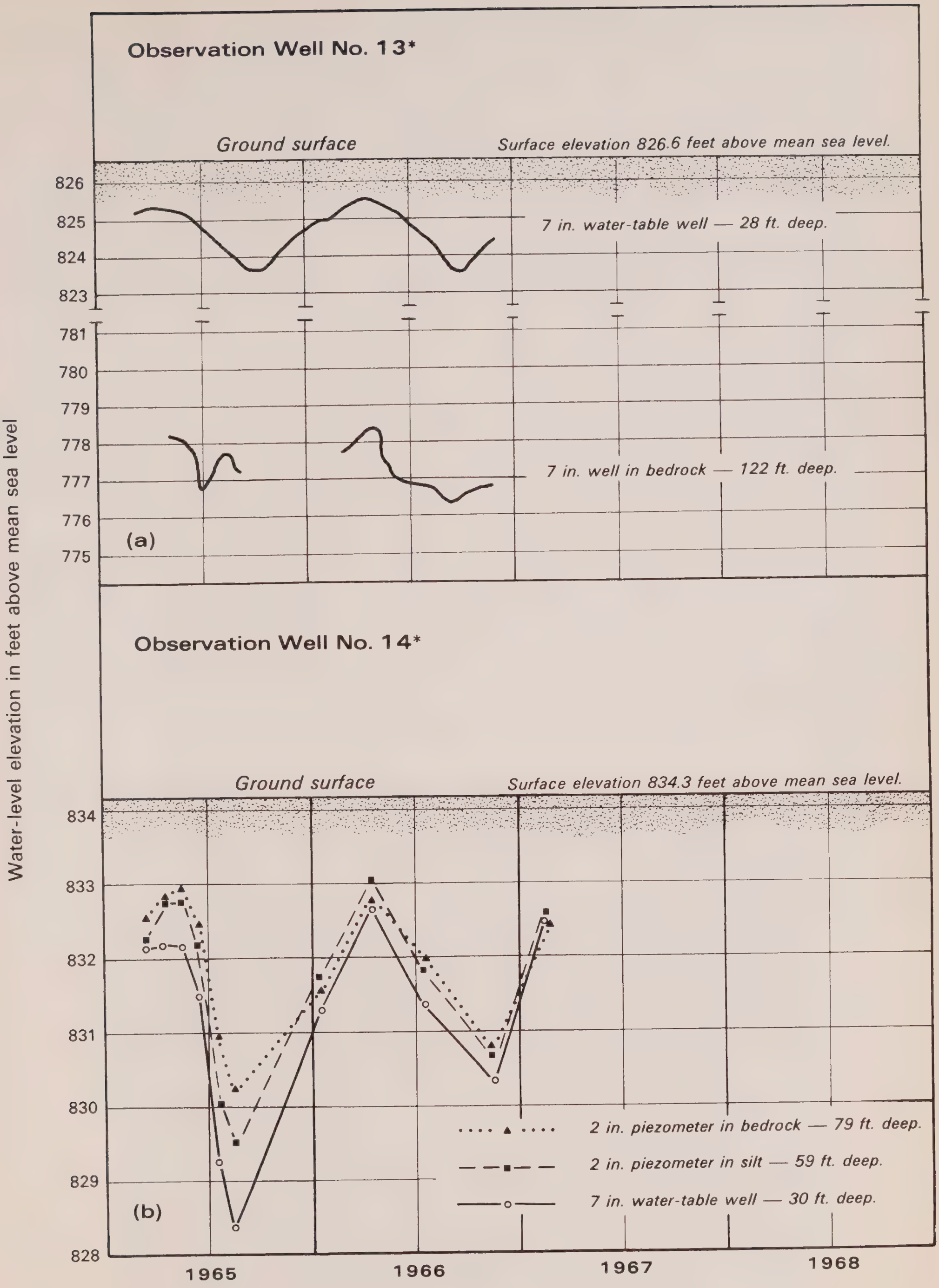


FIGURE 3—Relation between precipitation and average daily water-table elevation, Big Otter Creek basin.



* see Map 2705-7 for well location.

FIGURE 4—Seasonal variations of the water table, Big Otter Creek basin.



* see Map 2705-7 for well location.

FIGURE 5 — Monthly water-level elevation in two observation well nests, Big Otter Creek basin.

Figure 6 portrays the water-level profile of Big Otter Creek and six of its main tributaries (after Ontario Department of Planning and Development, 1957). Big Otter Creek has a total length of approximately 54 miles. Its extreme, stream-bed gradients vary from 3.7 feet per mile at its lower reaches to 67.5 feet per mile near its headwaters, with an overall average gradient of 8.3 feet per mile.

The main stream is flanked by flood plains of varying widths and V-shaped valleys of varying depths throughout its length. As the stream proceeds southward, it cuts continuously deeper into the overburden until at Vienna the Big Otter Creek streambed is about 100 feet below the surrounding landscape. Just below Bayham, the stream has carved three different stages of floodplains on its descent to the present water-level of Lake Erie.

General Streamflow Characteristics

The characteristics of the flow in a stream can be illustrated by streamflow hydrographs, graphs showing variations in monthly mean discharges, flow-duration curves, and by minimum- and flood-flow probability curves.

Dams may have a prominent effect on streamflow. Consequently, the location, number and type of dams in a watershed are important in the evaluation and explanation of particular streamflow characteristics in a basin.

In Big Otter Creek basin, two main types of dams exist: (1) small, earth dams, on tributary streams, that pond small amounts of water for domestic, stock and some irrigation uses; and (2) large, concrete or earth dams that pond amounts of water sufficient for recreation, water-supply and milling purposes. Map 2507-7 indicates the location of the main dams in the drainage basin. There are four large dams in the area — at Norwich, Otterville, Rock's Mill and Tillsonburg; all others are mainly small earth or log dams on tributaries of Big Otter and Little Otter creeks.

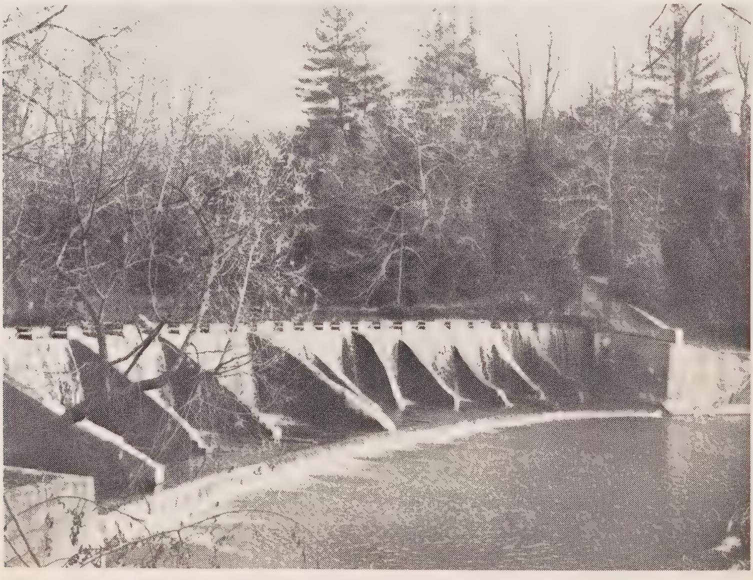


Plate 5 – Dam at Rock's Mills between Otterville and Tillsonburg; South Norwich Twp., Con. XI, Lot 21.

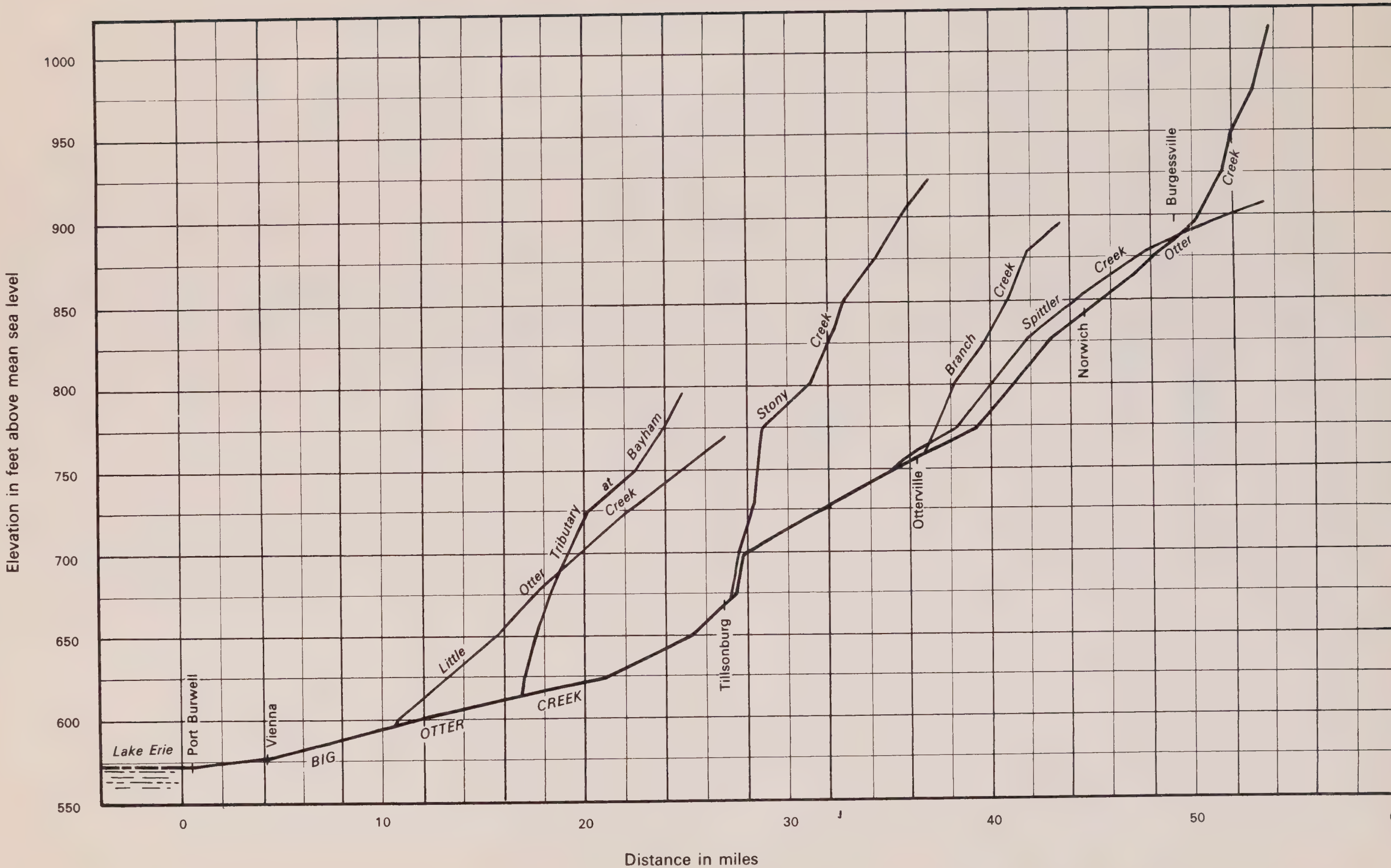


FIGURE 6 — Stream profiles, Big Otter Creek and main tributaries (after Ontario Department of Planning and Development, 1957).

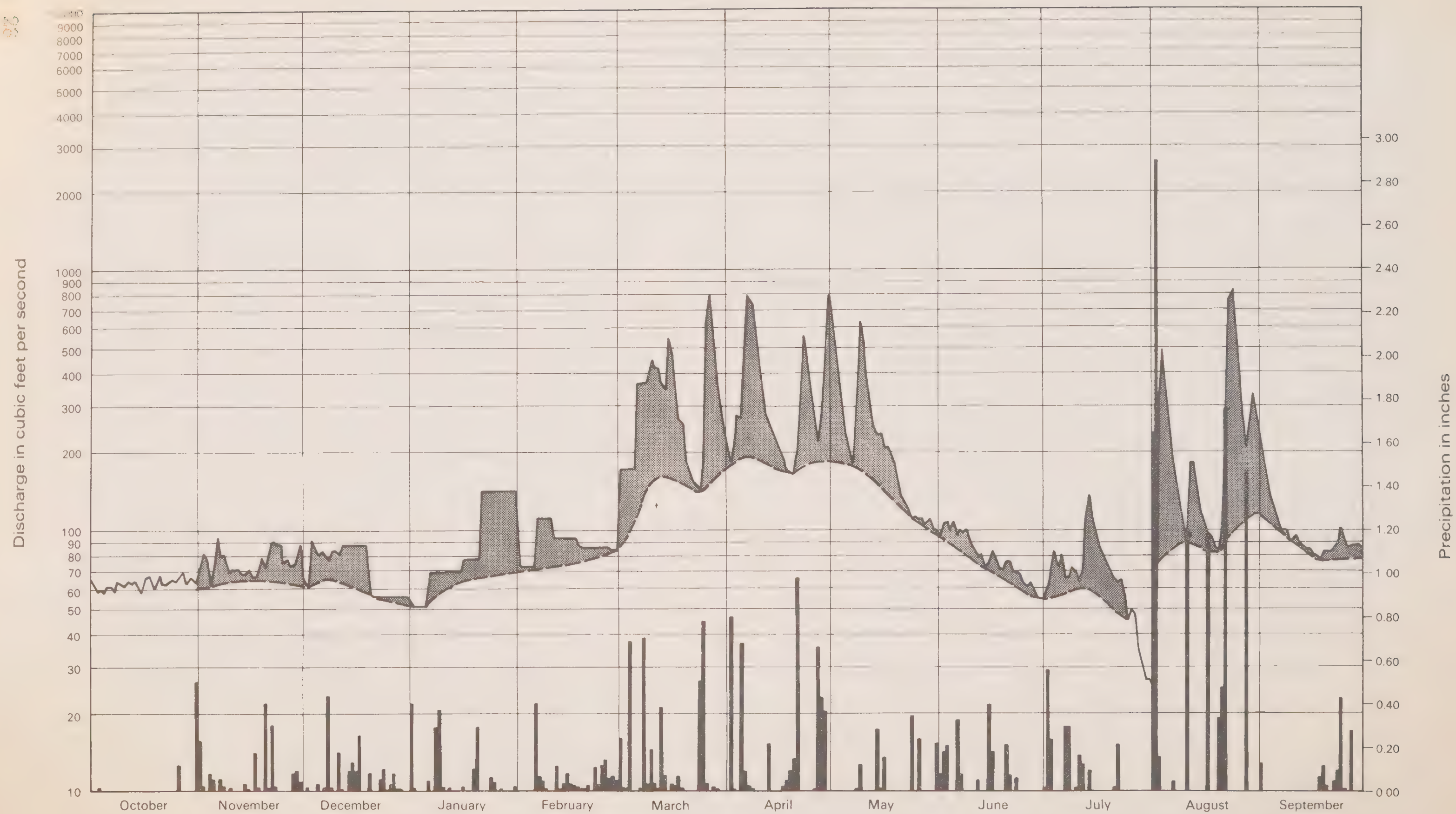


FIGURE 7a — Precipitation and streamflow hydrographs, Big Otter Creek at Vienna, for water year ending 1964.

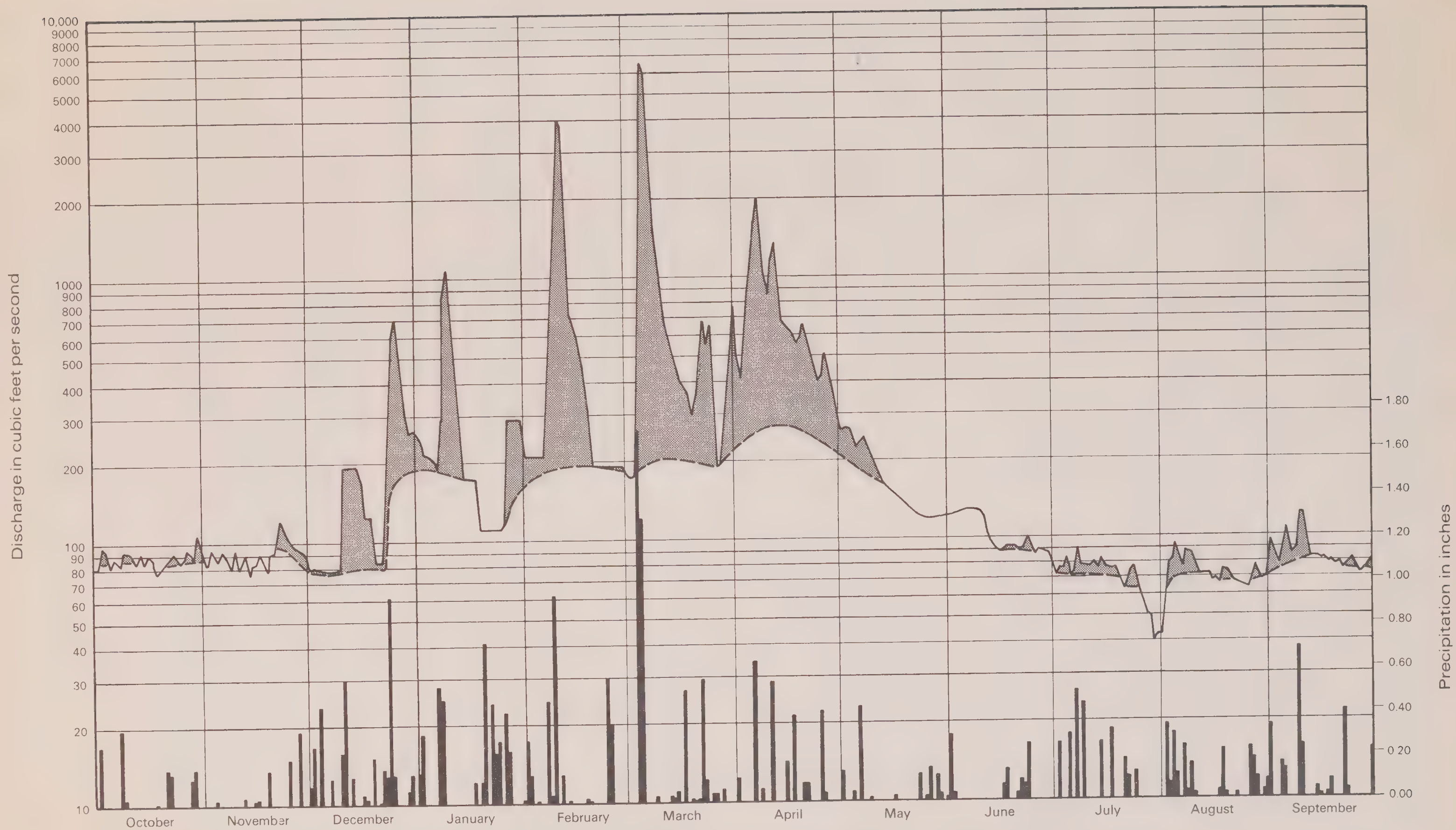


FIGURE 7b — Precipitation and streamflow hydrographs, Big Otter Creek at Vienna, for water year ending 1965.

For the most part, the effects of the existing dams on Big Otter Creek streamflow at Vienna and Tillsonburg seem to be negligible; however an awareness of the presence of these dams, and the effect that they may have on streamflow is important.

Figures 7a and 7b are the streamflow hydrographs for the Vienna streamflow gauging station (2GC-4) during the 1964 and 1965 water years. A water year ends September 30, at the end of the growing season, rather than December 31. Generally the highest streamflows occur during the spring months of March and April and then the stream is in recession until low flow is reached sometime during mid-summer. Streamflow was abnormally high during August, 1964, because of extremely high rainfall. During late fall, the flow is almost exclusively ground-water discharge, or "base flow".

Variations in the monthly mean discharge for the months of greatest variability are shown in Figure 8. The greatest variation, from year to year, in monthly mean discharge, is for March and April. The amplitude of the fluctuation decreases from the maximum in March and April to a minimum in August.

Flow-Duration Curves

A flow-duration curve is a cumulative frequency curve that shows the percentage of time during which specified discharges were equalled or exceeded. The curves are usually used to compare flow characteristics of different streams or to predict the distribution of future flows for water-supply and pollution studies. In using the curves for future predictions, the user must realize that for the prediction to be of practicable use, the factors controlling the flow of the stream, such as dam regulation and water extraction, must remain constant.

The method of construction of flow-duration curves is described by Searcy (1959). The years of streamflow record used for the Vienna station were from 1948 to 1965 inclusive, except for 1954 for which streamflow records were incomplete. The flow-duration curve for 17 years of record for the Vienna gauging site is shown in Figure 9. Flows during ice conditions are only estimates, and this affects the validity of the curve somewhat.

Generally the curve approximates a straight line except at the lower end. The slope of the straight line is relatively steep, denoting that the flow above the gauging site at Vienna is highly variable and that the flows in the range of the straight line are largely due to direct runoff. Deviation of the curve from a straight line (at the lower end) indicates an erratic pattern of flow, probably caused both by irrigation practices in July and August, and possibly by upstream reservoir storage.

The flattened slope near the lower end suggests a relatively steady base flow and a large amount of ground-water storage. Streams whose high flows come largely from snowmelt or streams with large flood-plain storage tend to have a flat slope at the upper end of the curve. This is not the case for the duration curve drawn for the Vienna gauging station. Although fairly heavy snows do occur in the winter throughout most of the basin, the snowmelt is sporadic. Consequently, the snowmelt does not seem to be a major source of spring runoff. The wide areas of sand next to Big Otter Creek absorb most of the snowmelt, leaving little for direct surface runoff.

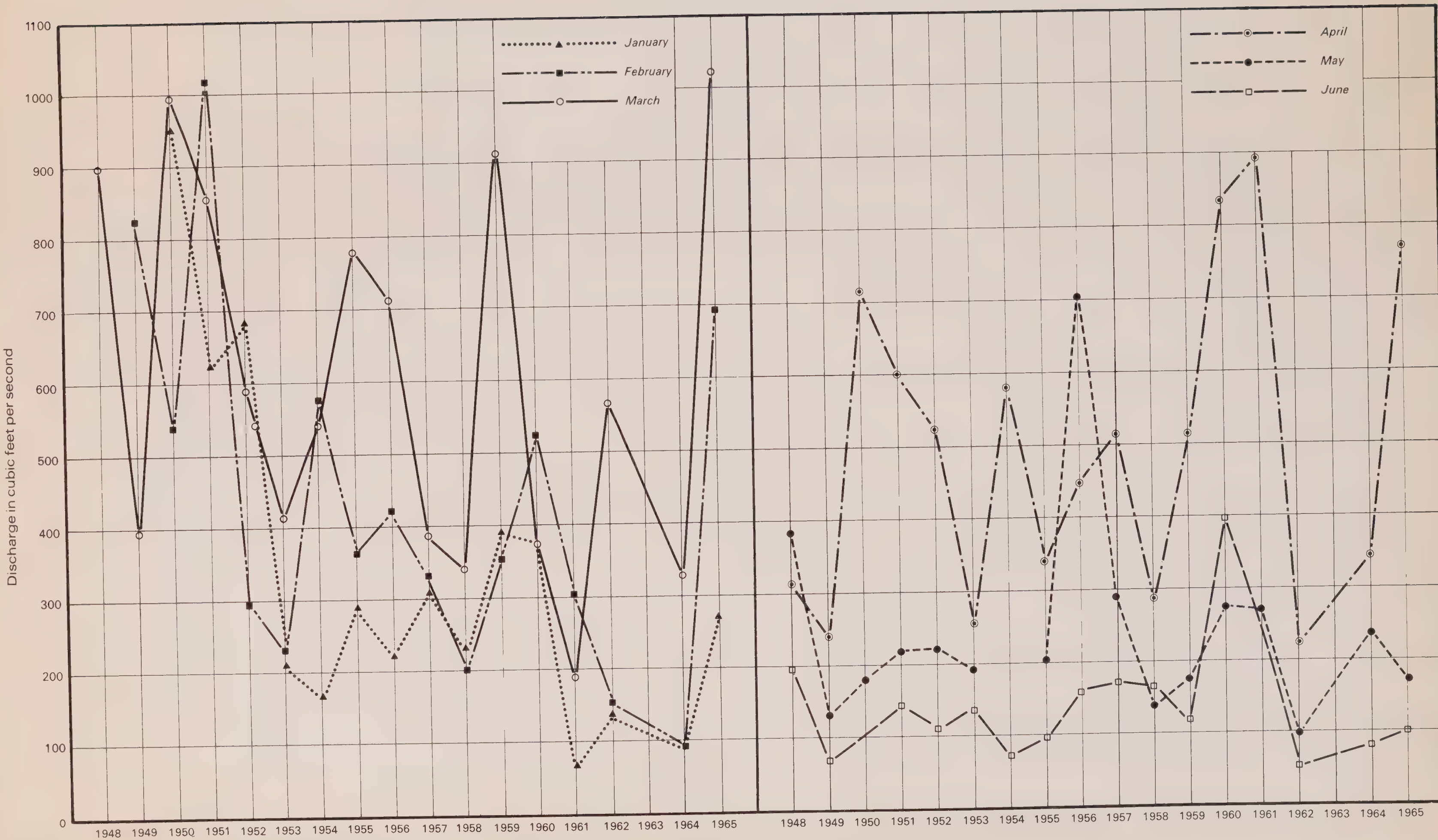


FIGURE 8 – Monthly mean discharge, Big Otter Creek at Vienna, for the months of largest variability.

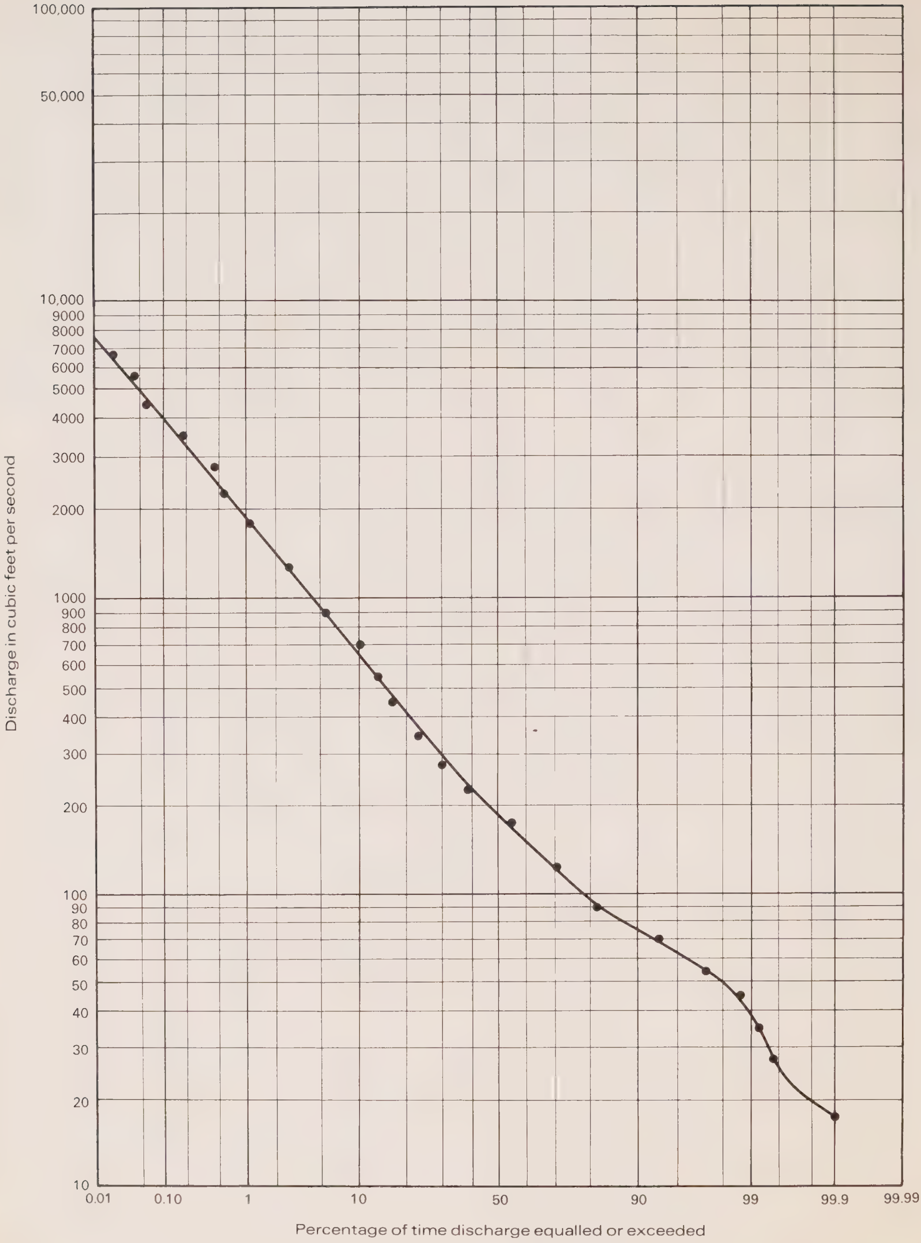


FIGURE 9 – Flow-duration curve, Big Otter Creek at Vienna (1948-1953, 1955-1965).

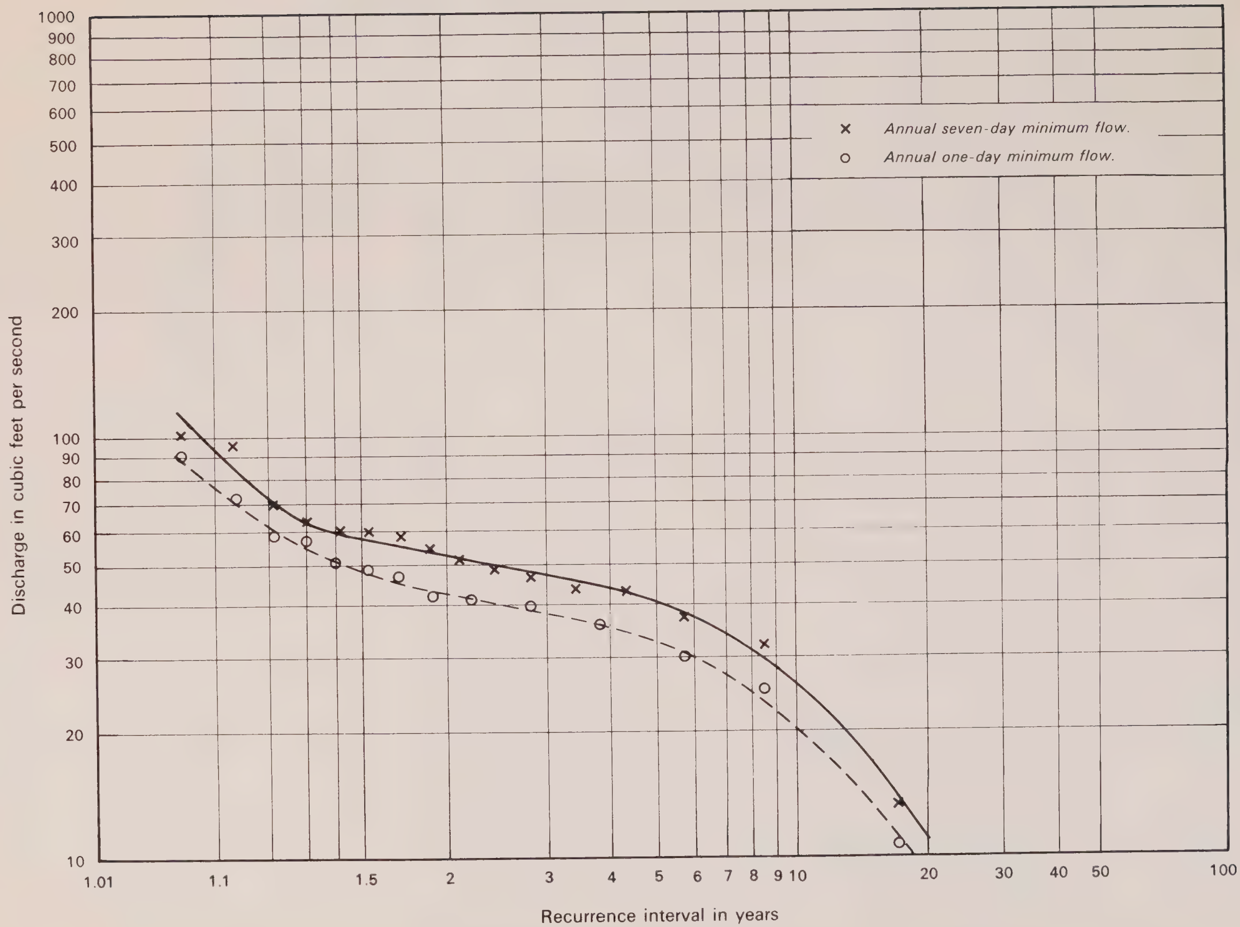


FIGURE 10 – Low-flow frequency curves, Big Otter Creek at Vienna (1948-1953, 1955-1965).

Low Flows

Annual one-day and annual seven-day minimum flow curves for Big Otter Creek at the Vienna gauging station are shown on Figure 10. Such minimum flow curves indicate the recurrence interval of annual, average low-flow discharges over one-day and seven-day periods. The recurrence interval, T, in years, is defined by the formula:

$$T = \frac{n + 1}{m}$$

as discussed by Dalrymple (1960, p.16).

The annual one-day and annual seven-day minimum flows occur during the irrigation periods in July and August and during the natural low flow period in September and October. The curves can be utilized to calculate the amount of storage required to maintain continuous rates of irrigation withdrawal from the stream during the critical period in July and August. To apply this method (for a specific point of withdrawal) a curve must be constructed for that point. Any planning of future withdrawals from the main and secondary streams should consider the range of minimum flows at the specific withdrawal site.

Figure 11 is a map indicating the lowest, annual, average seven-day minimum flow in Big Otter Creek and its main tributaries based on streamflow records and a series of spot measurements made in 1964 and 1965. The head waters and all tributaries of Big Otter Creek above the junction of Little Otter Creek had annual seven-day minimum flows of less than 1 cfs (cubic foot per second), and only the main stem of Big Otter Creek had more. However, the map shows that some flow was maintained in most larger streams despite the low rainfall. At the Vienna gauging station, the lowest, annual, average seven-day minimum flow for 17 years of record (1948 to 1965, excluding 1954) is 13.4 cfs.

Flood Flows

Floods in Big Otter Creek basin were noted as early as 1807. A comprehensive account of these early floods is given in the Otter Creek report (Ontario, Department of Lands and Forests, 1962).

The flood-frequency curve shown in Figure 12 was constructed using annual-flood series (Dalrymple, 1960). Momentary peak discharges at the Vienna gauging station were not available, so the highest daily mean discharge in a water year was used. Table 4 shows these in order of rank from 1949 to 1965, excepting 1963.

The flood-frequency curve can be used to calculate the probability of flooding at Vienna because the village is located on the flood-plain of Big Otter Creek. Flooding takes place when the stream discharge is so great it cannot be carried by the channel. This situation prevails at Vienna when the stream discharge exceeds 6200 cfs. The flood-frequency curve indicates this will occur on an average of once every 13 years.

The maximum mean daily flows have occurred most often in February, March and April. Although summer storms have produced high flows, these floods have not exceeded the maximum daily mean discharges occurring during the spring runoff period.

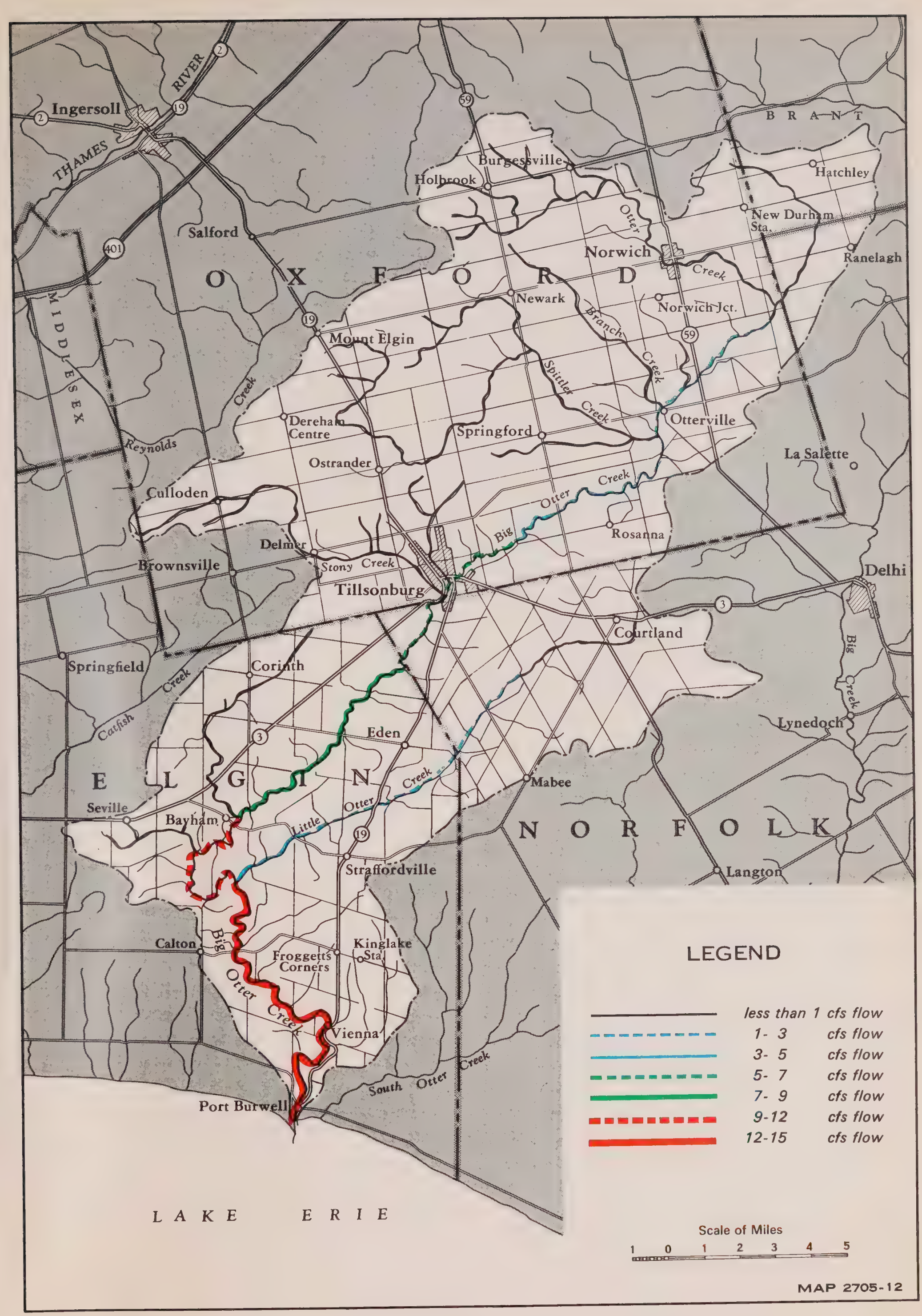


FIGURE 11 — Lowest annual seven-day minimum flow, Big Otter Creek and tributaries (1948-1953, 1955-1965).

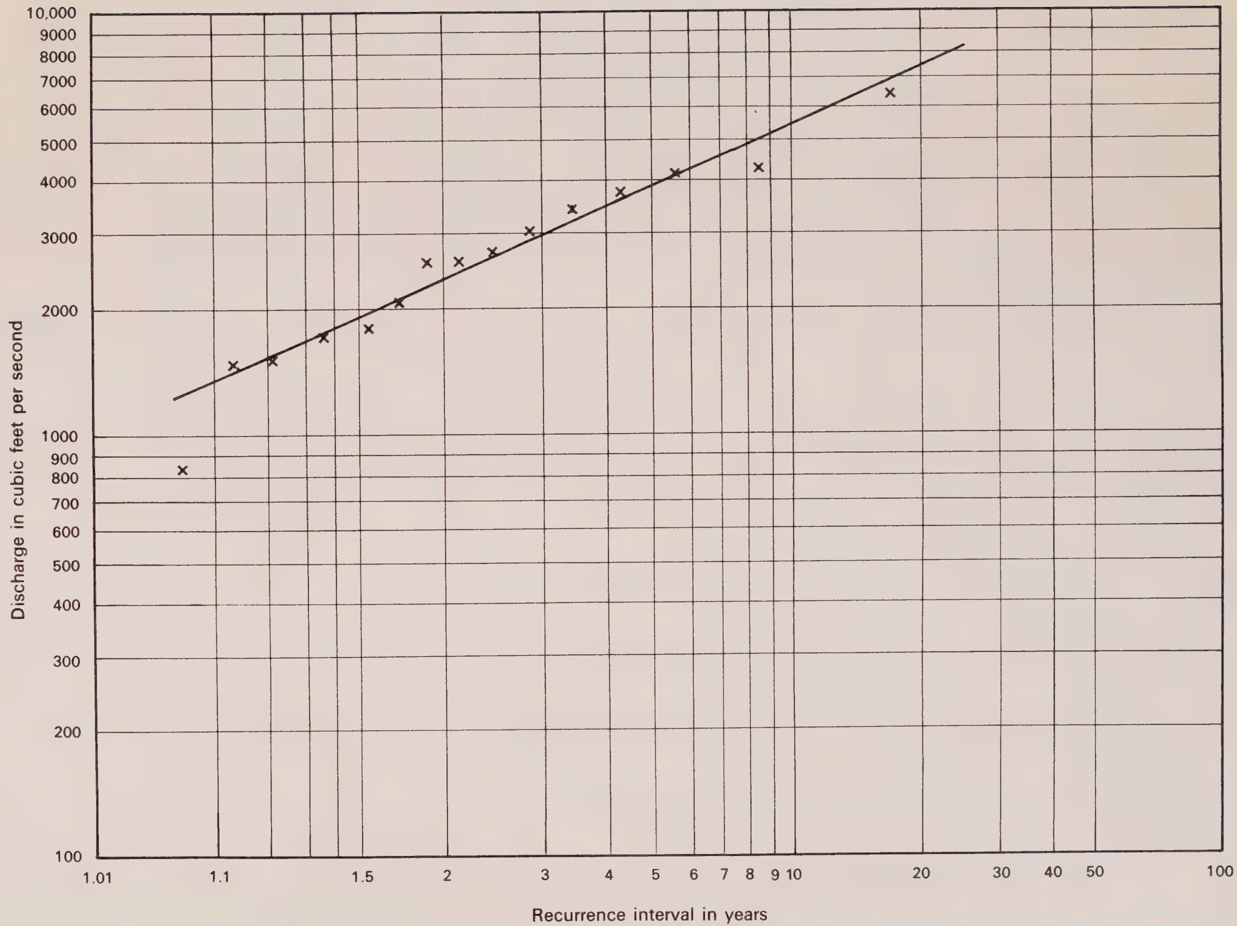


FIGURE 12 – Flood-frequency curve, Big Otter Creek at Vienna (1949-1962, 1964-1965).

Table 4. Annual Flood Data, Big Otter Creek at Vienna

Year	Date	Mean Daily Discharge (cfs)	Rank	Recurrence Interval (years)
1964	Aug. 24	839	16	1.06
1958	Dec. 27	1450	15	1.13
1959	March 21	1500	14	1.21
1962	March 11-15	1700	12.5	1.36
1953	March 4	1700	12.5	1.36
1961	April 26	1790	11	1.54
1957	April 6	2070	10	1.70
1955	March 1	2530	9	1.88
1956	March 3	2570	8	2.12
1960	March 30	2710	7	2.42
1952	March 11	3040	6	2.83
1951	Feb. 22	3400	5	3.40
1949	Feb. 16	3730	4	4.25
1950	April 5	4120	3	8.50
1954	Feb. 17	4230	2	5.66
1965	March 6	6400	1	17.00

Big Otter Creek Tributaries

Physiographic Descriptions

Six main tributaries flow into Big Otter Creek: Little Otter Creek, an un-named tributary at Bayham, Stony Creek, Spittler Creek, Branch Creek and Otter Creek. Of these, Little Otter Creek flowing just south of and parallel to the "Paris moraine" is the longest. It joins Big Otter Creek about three miles south of Bayham. Most of the area drained by this creek is a sandy plain in which the depth of the V-shaped valley increases downstream to 125 feet at the confluence with Big Otter Creek. A relatively wide flood plain forms the bottom of the valley throughout its length.

The tributary that enters Big Otter Creek from the west, just above Bayham, is relatively short and has a wide and very steep valley near its mouth. Stony Creek is a small creek that drains a relatively flat sandy area and enters Big Otter Creek from the west at Tillsonburg. Branch Creek, entering about a mile south of Otterville, and Otter Creek, entering about three miles southeast of Norwich, drain the relatively flat, undulating till and sand plains that make up the northern part of the basin. They flow through shallow floodplains except near their mouths where they flow through deeper, V-shaped valleys.

Table 5. **Spot-Discharge Measurements of Big Otter Creek Tributaries**

Date	Gauging Stations and Discharge in cubic feet per second				
	Tributary at Bayham O-3	Stony Creek O-4	Spittler Creek O-5	Branch Creek O-6	Otter Creek* (O-7 minus O-8)
1965					
May 11	5.35	—	—	—	—
12	—	5.25	14.67	2.79	—
19	—	—	6.71	1.38	6.12
20	3.62	4.17	—	—	—
26	3.00	—	—	0.63	6.26
June 9	2.04	1.74	2.82	0.59	5.65
15	1.88	1.51	2.12	0.37	2.94
22	2.06	1.34	1.95	0.35	3.95
July 8	2.23	1.14	0.39	0.36	—
22	1.21	0.57	1.15	—	—
23	—	—	—	0.35	3.95
Aug 11	1.36	—	1.84	—	—
12	—	0.86	—	0.23	2.59
25	1.12	1.21	1.68	—	2.13
Sept 23	2.01	1.82	—	—	2.41
24	—	—	2.00	0.42	—
Oct 20	1.94	0.94	3.00	0.57	4.54
Nov 23	9.76	—	—	—	—
24	—	10.10	21.76	5.33	11.24
Dec 15	23.5*	27.39	110.38	16.48	—
1966					
Jan 12	4.90	6.30	14.82	2.20	8.36
Feb 10	8.83	8.75	—	—	7.45
11	—	—	5.34	1.04	—
Mar 9	12.85	—	—	—	—
10	—	18.62	50.75	9.73	32.49
Apr 4	—	17.65	44.12	8.01	26.79
5	13.44	—	—	—	—
May 11	5.52	—	12.35	2.19	9.46
12	—	11.13	—	—	—

* estimated

Little Otter Creek Streamflow

The automatic recording station 2GC-15, 1.5 miles west of Straffordville (Map 2705-7), records streamflow derived from a drainage area of 42.3 square miles peripheral to Little Otter Creek. This gauging station was established in October, 1963, by the Canada Department of Northern Affairs and National Resources.

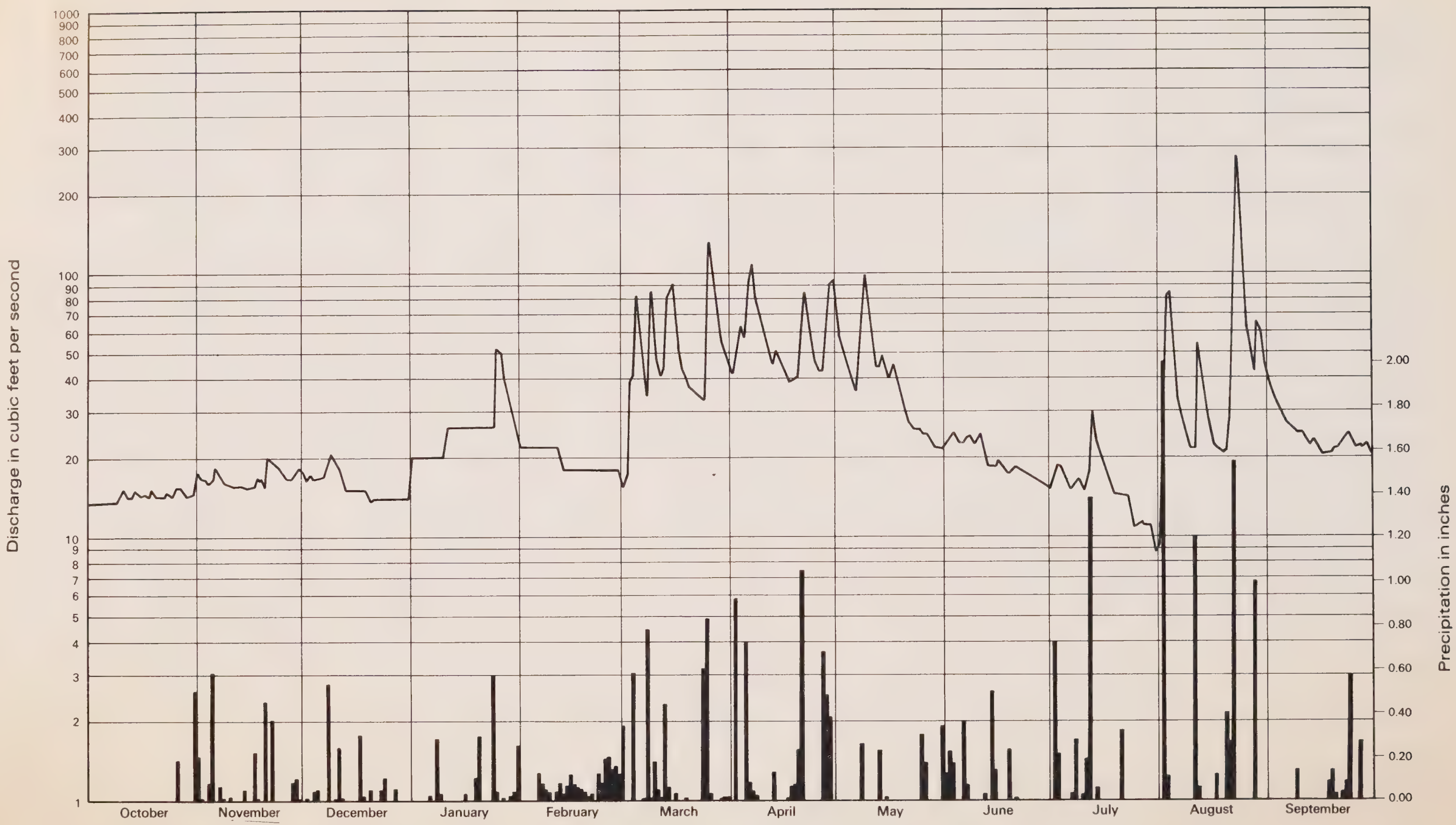


FIGURE 13a — Precipitation and streamflow hydrographs, Little Otter Creek near Straffordville, for water year ending 1964.

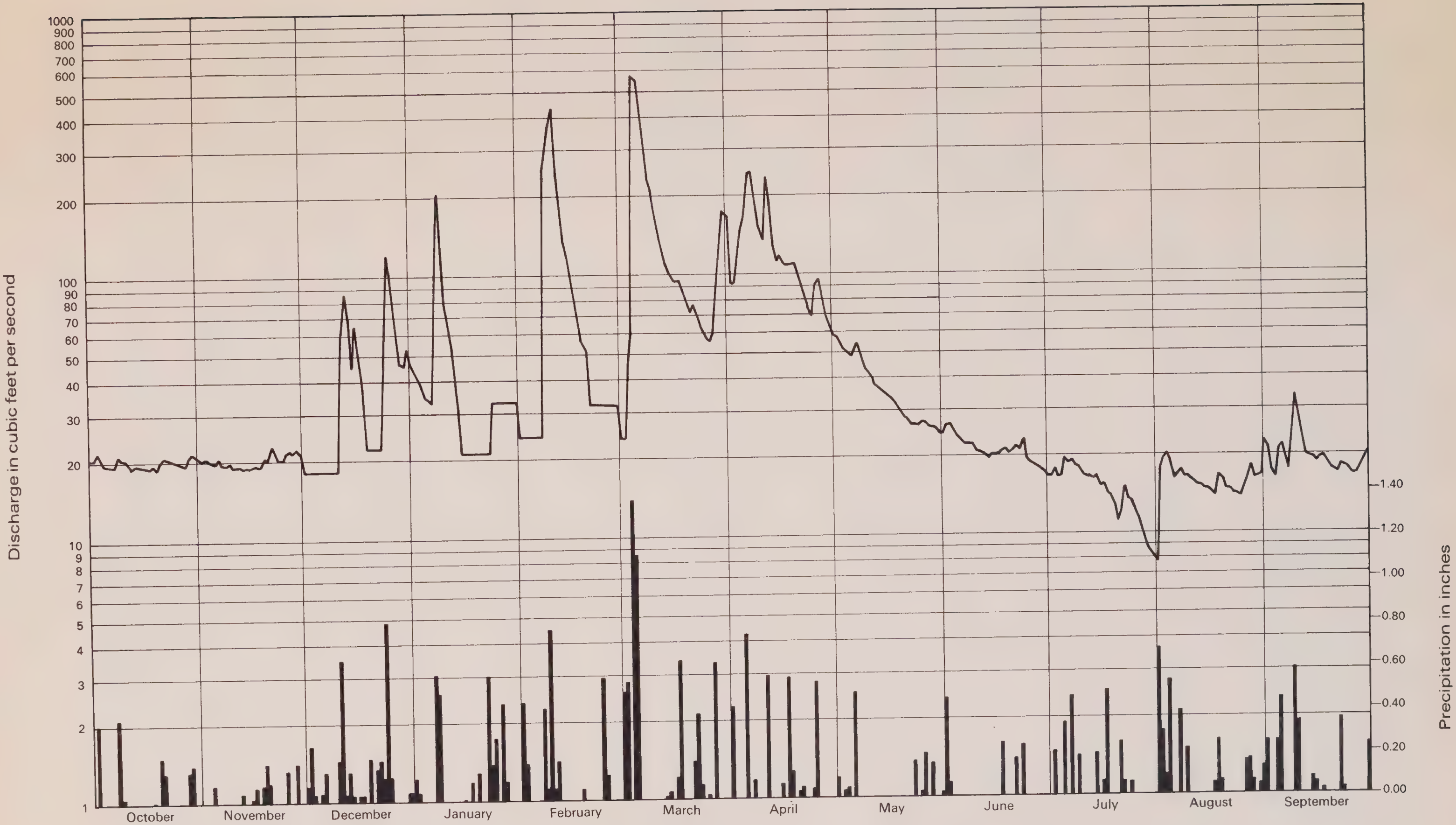


FIGURE 13b — Precipitation and streamflow hydrographs, Little Otter Creek near Straffordville, for water year ending 1965.

Hydrographs for the water years ending in September 1964, and September, 1965, are shown in Figures 13a and 13b. High flows occur during the spring months of March, April and early May and during the latter part of August. The lowest flows occur during the irrigation period — the last two weeks in July and the first week in August. The lowest one-day mean discharge of 8.1 cfs occurred on July 31 and August 1 (during the period of irrigation). Natural low streamflow occurs during the period from September through to December.

In general, the behaviour of the flow in Little Otter Creek is much the same as that of Big Otter Creek, i.e., the form of the hydrographs at 2GC-15 (Figures 13a and 13b) is very similar to that of the hydrographs of the station at Vienna (Figures 7a and 7b) on Big Otter Creek.

Streamflow in Other Tributaries

Periodic discharge measurements, primarily for the purpose of low-flow evaluations, were made by the Ontario Water Resources Commission during 1965 and 1966 on Otter Creek, Branch Creek, Spittler Creek, Stoney Creek and the tributary at Bayham, and are shown in Table 5. The locations of these stations are indicated on map 2705-7. According to the spot flow measurements, Branch Creek has the lowest flows; Spittler Creek generally the highest. The flow in Spittler Creek is mainly ground water derived from sands and silts exposed in the walls of the valley. Contact springs were observed at many places. The headwaters of all these streams are intermittent.

Hydrologic Budget

Definition

The hydrologic budget may be considered as a quantitative statement of the balance between the amount of water entering and amount of water leaving a drainage basin over a specified period of time. The general hydrologic budget equation may be written as:

$$P = R + ET \pm U \pm S_{gw} \pm S_{sm} \pm S_{sw}$$

where P = precipitation
R = streamflow
ET = evapotranspiration
U = underflow, into or out of the basin
S_{gw} = change in ground-water storage
S_{sm} = change in soil-moisture storage
S_{sw} = change in surface-water storage (includes snow and ice)

If a water-year budget period is considered, changes in ground-water, soil-moisture and surface-water storage are usually regarded as negligible. Underflow may occur across the basin boundaries, and through permeable alluvium at a stream-flow gauging site. Geologic evidence indicates it is low in the Big Otter Creek basin, and it was therefore disregarded. Hence, the main items of the budget are: precipitation, streamflow, and evapotranspiration. The 1964-65 water year hydrologic budget is calculated to demonstrate the relative importance of the items in the budget equation.

Precipitation

Precipitation, in the form of rain and snow, is the main source of all water in the basin. Three meteorological stations were used to calculate monthly normal precipitation values for Big Otter Creek basin. These were at Delhi, Woodstock and St. Thomas. Using the Thiessen polygon method, the following 30-year monthly normal (1931-1960) precipitation values for the basin were calculated:

Month	Normal Precipitation (inches)
January	3.02
February	2.99
March	3.09
April	3.51
May	3.30
June	2.92
July	3.03
August	3.10
September	3.19
October	2.92
November	2.97
December	3.02

The uniform distribution of precipitation throughout the year is an important feature of the hydrology of the region. The total precipitation for the 1964-65 water year was 30.81 inches, 6.85 inches below the calendar-year normal.

Streamflow

Streamflow in the basin consists of two main components: direct runoff, which is precipitation that reaches the stream channel rapidly by overland flow and is discharged from the basin within a short period, and ground-water runoff, which is precipitation that infiltrates into the soil, reaches the water table and then moves slowly towards the stream.

Ground-water runoff into streams, generally known as "base flow", plays a major role in sustaining flow in the streams during periods of drought. Accurate calculation of base flow in the drainage basin is hindered by irrigation practices during summer, by ice conditions during winter, and by frequent rains which limit flow recession to very short periods; however, approximate base-flow hydrographs at Vienna have been prepared (Figures 7a and 7b). The monthly and annual base flows for the water year ending in 1965 were calculated and are summarized in Table 6.

Table 6. Account of Hydrologic Budget Items by Months for 1964-65 Water Year, Big Otter Creek Basin

Month	Precipitation (P) (inches)	Streamflow at Vienna (R) (inches)			P - R (inches)
		Direct Runoff	Base Flow	Base Flow as % of Total Runoff	
October, 1964	1.30	0.02	0.36	95	0.92
November	0.78	0.02	0.35	95	0.41
December	3.94	0.34	0.48	59	3.12
January, 1965	4.17	0.51	0.64	56	3.02
February	3.10	1.92	0.77	29	0.41
March	5.01	3.51	0.86	20	0.64
April	2.59	2.18	1.02	32	– 0.61
May	1.12	0.10	0.62	86	0.38
June	1.00	0.01	0.41	98	0.58
July	2.52	0.06	0.24	80	2.22
August	2.98	0.05	0.26	84	2.67
September	2.30	0.07	0.28	80	1.95
Total	30.81	8.79	6.31	Average = 42	15.71

Figure 14 indicates the general flow-recession curves for the Vienna and Tillsonburg gauging stations. Each curve reflects the decline of streamflow brought about by two independent processes: recession of direct surface-water runoff and recession of base flow. Attempts to relate base flow discharge and ground-water stage in Big Otter Creek basin proved to be inconclusive, and subdivision of the general flow-recession curves into surface- and ground-water discharge was not achieved. The lowest estimated base flow during the year was approximately 60 cfs.

The total runoff, as measured at Vienna for the 1964-65 water year, was 15.10 inches.

Evapotranspiration

Evapotranspiration consists of the natural process of evaporation and the process of transpiration, i.e., the discharge of moisture into the atmosphere through plants. The rate of evapotranspiration depends mainly on solar radiation, air temperature, wind velocity, availability of moisture, the character of the land, and plant cover.

It is practically impossible to measure evapotranspiration directly; however, evapotranspiration can be calculated indirectly by using the hydrologic budget equation by assuming that the annual change in ground-water, surface-water, and soil-moisture storage are all negligible. With the above assumptions, the

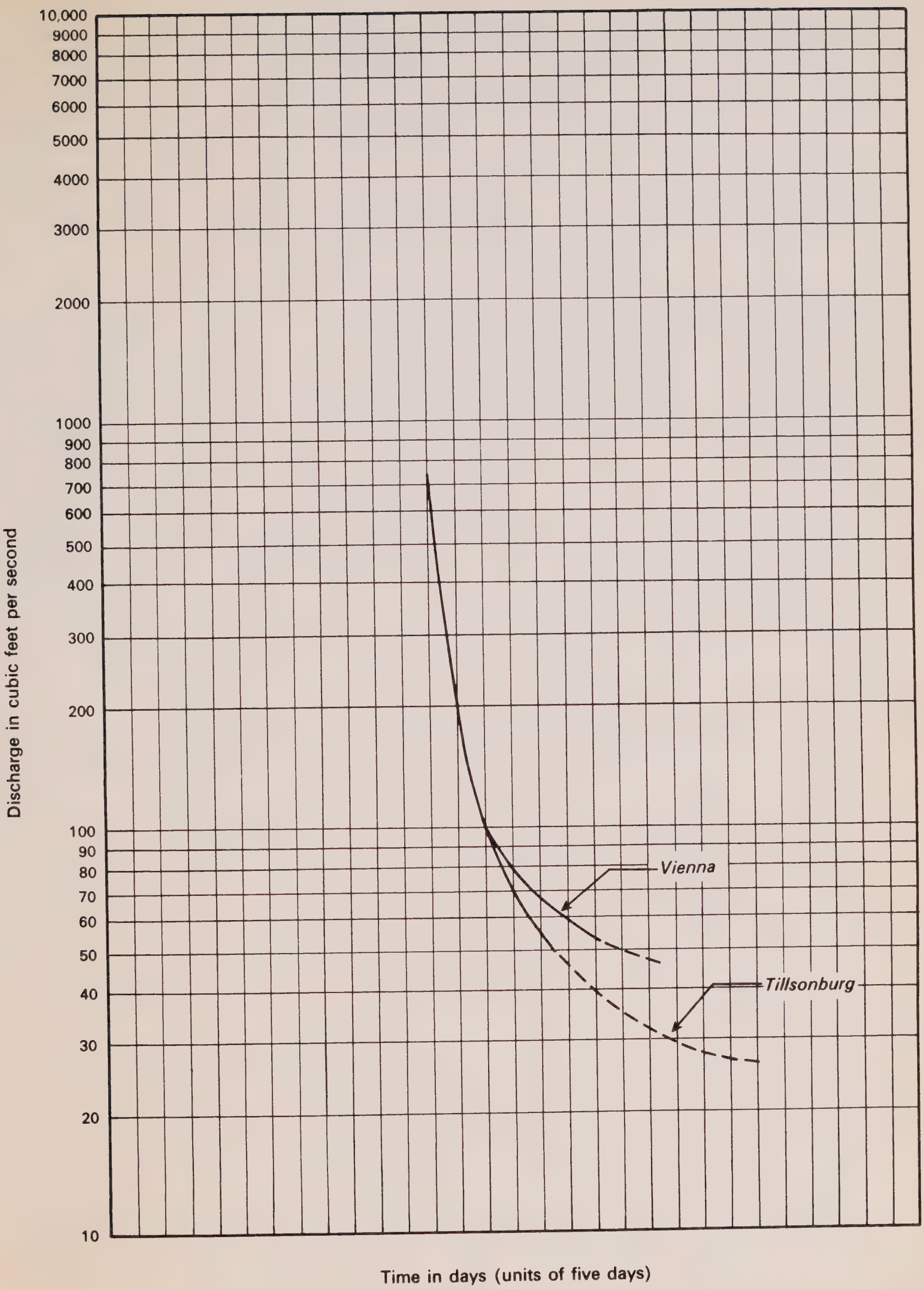


FIGURE 14 – Streamflow-recession curves, Big Otter Creek at Vienna and Tillsonburg.

following equation gives an approximate value for evapotranspiration and is applied to the Big Otter Creek basin for the water year ending September 30, 1965:

$$ET = P - R$$

where ET = evapotranspiration (inches)
P = precipitation over the basin (inches)
R = stream discharge out of the area (inches)

From Table 6 the evapotranspiration in Big Otter Creek basin for the 1964-65 water year was 15.71 inches.

A number of empirical formulas have been developed to estimate evapotranspiration and potential evapotranspiration under various field and meteorological conditions (Viehmeyer, 1964). Potential evapotranspiration is the total amount of water that would be utilized by the plants in the basin if it were available.

Table 7 is a tabulation of the monthly temperature and possible daylight hours for Delhi and the monthly potential evapotranspiration values as calculated by the Thornthwaite method using these meteorological data. The difference between this value for potential evapotranspiration and evapotranspiration as calculated by the water budget for the water year ending in 1965, is 7.66 inches. This is an indication of the additional water needed during this relatively dry year to satisfy annual potential evapotranspiration in the basin.

Table 7. Potential Evapotranspiration by the Thornthwaite Method

Month	Mean Monthly Temperature (°F)	Possible No. of Daylight Hours (hrs.)	Potential Evapotranspiration (inches)
October, 1964	46.7	338	1.45
November	41.2	292	0.77
December	23.2	282	nil
January, 1965	27.9	294	nil
February	21.2	294	nil
March	27.3	374	nil
April	38.8	406	0.71
May	59.2	454	3.48
June	64.2	457	4.30
July	64.9	462	5.06
August	66.2	426	4.28
September	62.5	371	3.32
Total			23.37

Change in Ground-Water Storage

The change in ground-water storage for the 1964-65 water year is not known. However, the annual change in the piezometric surface is very small (Figures 5(a) and 5(b)). Similarly, seasonal elevations of the water-table for different years can be very close, as was the case in August, 1965, to August, 1966, (Figure 3). Hence, the assumption of little annual change in ground-water storage for the water year ending in 1965 seemed valid and the term S_{gw} was neglected in the account of the annual hydrologic budget.

Summary

A simplified form of the standard hydrologic budget equation was used to arrive at the relative values of the hydrologic parameters of precipitation, runoff and evapotranspiration. The parameters of underflow and the changes in ground-water, surface-water, and soil-moisture storage were assumed to be negligible and were not determined for the 1964-65 water year. Total precipitation and total stream runoff were the only field-measured quantities in the equation. "Evapotranspiration" represents actual evapotranspiration in the basin and all other parameters that might have been significant but were neglected from quantitative evaluation. The following tabulation is a quantitative summary of the simplified hydrologic budget for the 1964-65 water year in the Big Otter Creek basin:

Water Into Basin (inches)		Water Out of Basin (inches)		
Precipitation*	30.81	Streamflow	— surface runoff	8.79
			— base flow	6.31
			Total	15.10
		Evapotranspiration and all other changes		15.71
TOTAL	30.81		TOTAL	30.81

* Precipitation for this period was 6.85 inches below normal.

In the evaluation of the two components of streamflow — surface runoff and base flow — the base flow was determined to average 42 per cent of the total streamflow during the water year; however, monthly base flows ranged as high as 95 per cent of total runoff in October and November and as low as 20 per cent of runoff in March. The values indicate a high percentage of base flow during summer and fall, and a low percentage during spring.

The potential evapotranspiration, as calculated by the Thornthwaite method, was 23.37 inches or 7.66 inches above the "evapotranspiration" as calculated by the simplified budget equation.

WATER QUALITY

Introduction

Water quality in the Big Otter Creek drainage basin is an important factor in domestic and agricultural uses. Although the demand for certain quantities of water can often be met, the use of water can be limited by quality requirements. In the Big Otter Creek drainage basin the main withdrawal uses of water are domestic, irrigation, and industrial. The chemical quality standards for industrial water supplies vary widely and in this report no consideration is given to industrial requirements different from those for domestic or irrigation purposes.

The main purpose of this section on chemical quality of ground and surface water is to discuss the suitability of the sampled waters for domestic and irrigation uses.

Rainwater that reaches the surface of the earth percolates through soil or runs off the surface of the ground. During these processes, initial dissolution of minerals takes place. The eventual concentration of dissolved minerals depends primarily on the amount of water in circulation, the initial concentration of elements already dissolved in the water, the chemical composition of the overburden or rock, the distance the water moves, and the rate of this movement. The latter two, distance and rate of movement, determine the time of contact of the water with its medium.

According to Toth (1963), three possible scales of ground-water flow systems — local, intermediate and regional — can exist in a drainage basin. Ground water moving in each system can have a different rate of movement and therefore a different time of contact with soil or rock materials. Water samples taken from either different flow systems or different points in the same flow system, display chemical properties characteristic of their history in the flow system.

Water samples were taken from 34 wells ending in overburden, and 14 wells ending in bedrock aquifers. The wells were used to obtain water samples representative of the quality of ground water at different depths and at different locations in the basin. Seven water samples were taken from stream sampling points at the mouths of the main tributaries and the lower reaches of Big Otter Creek and one sample was taken from Lake Erie at Port Burwell.

The locations of the sampling points and chemical quality of the samples are shown graphically on Map 2705-9. The results of the chemical analyses are tabulated in Appendix B. The specific electrical conductance values are reported as micromhos per cubic centimentre at 25°C. All other values in the tables, except pH, are reported as "parts per million" (ppm). One part per million represents 1 milligram of solute in 1 kilogram of solution, a weight-to-weight relationship. "Equivalents per million" (epm) is used to indicate and compare ionic concentrations in water. The ppm values can be converted to epm by using the following formula:

$$\text{epm} = \text{ppm} \times \frac{\text{ion charge (valence)}}{\text{atomic or molecular weight of ion}}$$

Hardness and alkalinity values (in ppm) are reported as $CaCO_3$, nitrate nitrogen as N^{5+}, and all other constituents as the appropriate ion: sulphate as SO_4^{--}, calcium as Ca^{++}, magnesium as Mg^{++}, potassium as K^+, sodium as Na^+, and chloride as Cl^-. The alkalinity of waters in the basin is due to the bicarbonate radical, HCO_3^-.

Suitability of Water for Domestic and Stock Use

Some elements occurring in natural waters are detrimental to human health if present in excessive concentrations. Characteristics of water such as, colour, turbidity, odour and taste are not necessarily harmful but may be objectionable. According to the chemical parameters which were analysed, the Ontario Water Resources Commission (1967) drinking water objectives for human consumption are as follows:

Constituent	Recommended Maximum Limit of Concentration (ppm)
Chloride (Cl)	250.0
Iron (Fe)	0.3
Nitrate (NO_3)	45.0
Sulphate (SO_4)	250.0
Total dissolved solids	500.0

Waters that meet the requirements for domestic purposes are assumed to be suitable for stock watering.

A brief discussion of the individual constituents is presented below.

Chloride

Figure 15 shows the areal distribution of sampling points and corresponding concentration of chlorides present in the samples from overburden wells. Chloride concentrations ranged from 3 to 191 ppm with an average value of 21 ppm.

The samples from wells ending in bedrock, or just on top of the bedrock, contained low chlorides at the northern end of the basin (2 ppm in well 20) and increased considerably toward the south (440 ppm in well 530).

The range of chlorides in the surface-water samples was from 9 ppm to 24 ppm.

Iron

The total iron concentration in 9 ground-water samples from overburden wells showed large areal variations (Figure 16). Seventeen samples contained less than 0.30 ppm and ranged from 0.10 to 0.30 ppm. Twenty-two samples had concentrations in excess of 0.30 ppm and ranged up to 5.5 ppm. No noticeable correlation seems to exist between the amounts of iron and the types of aquifer the wells tapped.

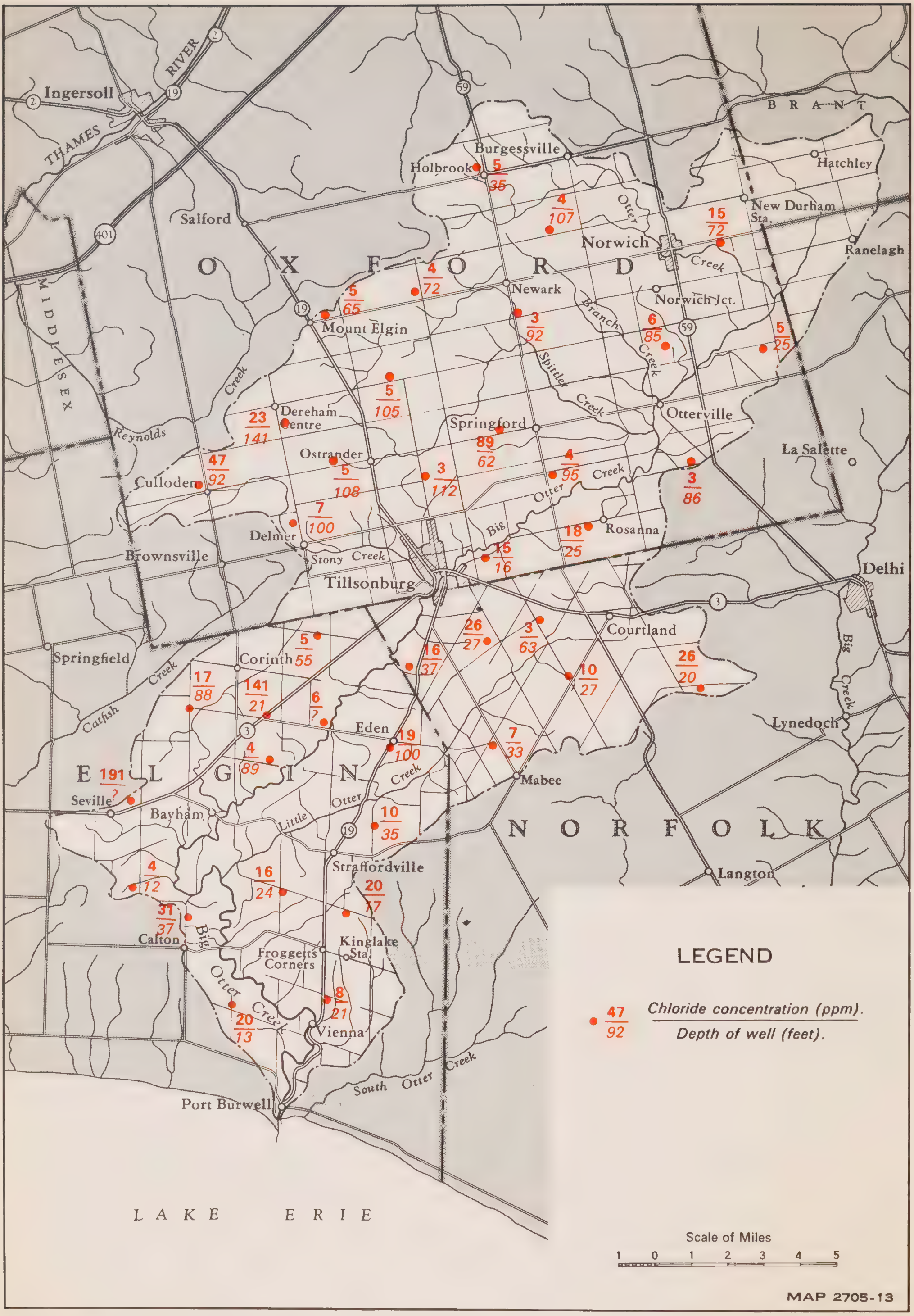


FIGURE 15—Chloride concentration in representative overburden wells, Big Otter Creek basin.

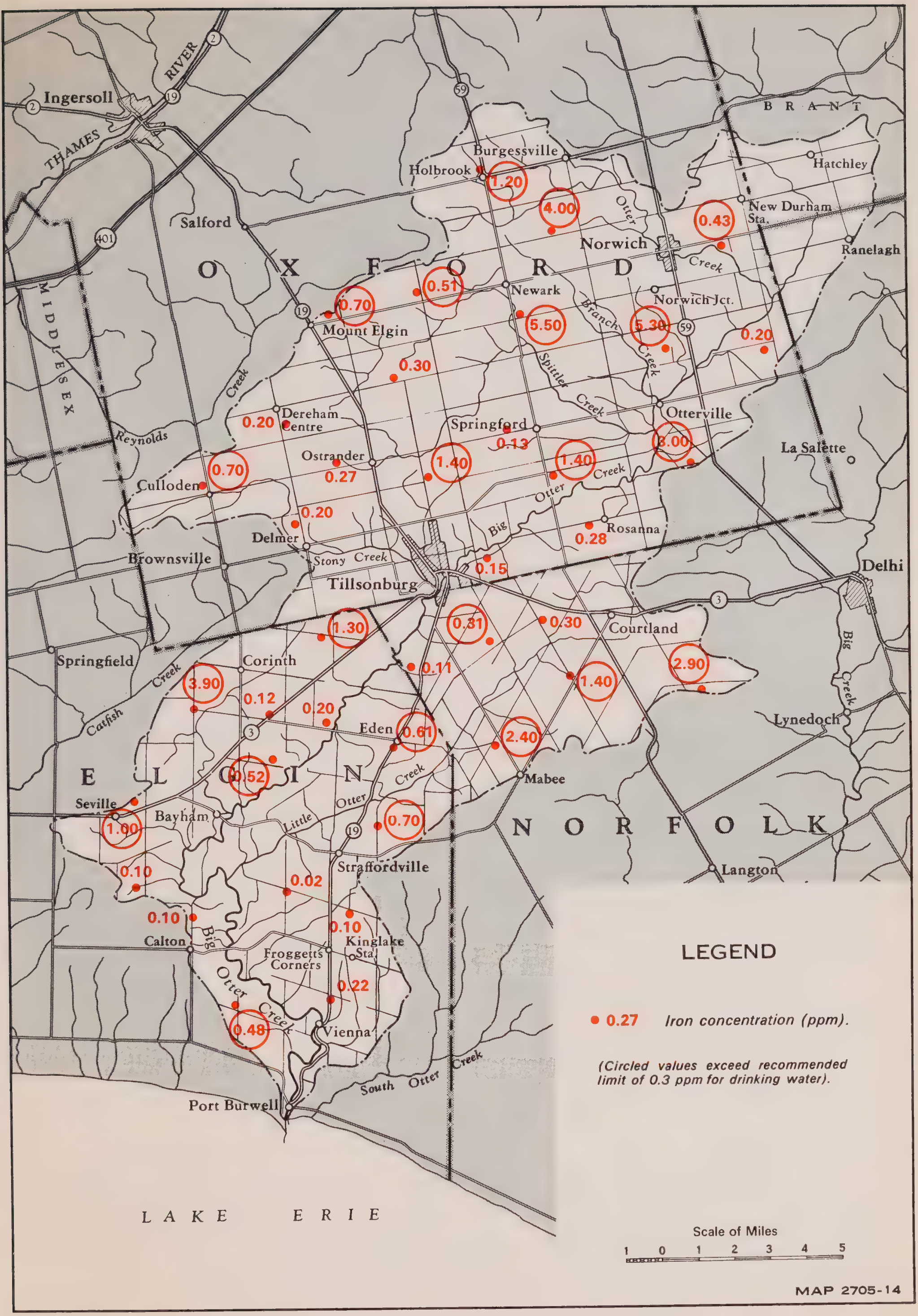


FIGURE 16 —Iron concentration in representative overburden wells, Big Otter Creek basin.

The range of iron concentrations in bedrock-water samples was smaller; 0.10 ppm to 3.9 ppm with a mean of 0.84 ppm.

Surface-water samples contained iron ranging from 0.11 to 3.3 ppm with a mean of 0.64 ppm. Generally, the frequency of high iron concentrations was much greater in surface-water samples than in ground-water samples.

Nitrate

Nitrogen occurs in many forms in water and may indicate contamination from sewage, barnyard waste or fertilizers. Waters containing nitrogen (as N) in excess of 10 ppm may cause *methemoglobinemia* ("blue babies") when consumed by infants. In this report, only the nitrogen in the nitrate radical, NO_3^-, is reported. Ten ppm nitrogen is contained in approximately 45 ppm NO_3^-.

Twenty samples of the overburden ground waters contained nitrate nitrogen from 0.15 ppm to 30 ppm with an average value of 1.7 ppm. Two of these wells (wells 539, 222, see Map 2705-1) in the southern half of the basin had a fluctuating nitrogen concentration in excess of 10 ppm.

Nitrate nitrogen was reported from only one rock well; the water contained 2.0 ppm.

Nitrate nitrogen values in the stream samples ranged from 0.40 to 0.60 ppm with a mean value of 0.48 ppm.

Sulphate

All shallow ground waters in the basin contain less than 250 ppm sulphate. The mean sulphate values from three different sources were: overburden wells — 72 ppm; bedrock wells — 43 ppm; surface water — 48 ppm. Most bedrock waters in the basin, especially those from the Delaware formation, contain detectable amounts of hydrogen sulphide.

Total Dissolved Solids

The total dissolved solids concentrations of 34 samples from overburden wells are shown in Figure 17. Total dissolved solids in these samples ranged from 182 to 814 ppm. Six samples contained total dissolved solids above the 500 ppm recommended limit for potable water; the mean value for these samples was 609 ppm.

The total dissolved solids in rock wells ranged from 246 ppm to 1064 ppm with an average value of 447 ppm. Generally, the total dissolved solids in the rock wells increase with overburden thickness.

The total dissolved solids in surface water samples had a relatively small range — 280 to 364 ppm, with an average of 333 ppm.

Hardness

Hardness is a parameter of water quality that is generally not considered injurious to human health, but very hard water creates problems in industrial and domestic use. In industry, water of high carbonate hardness deposits an objectionable scale in boilers and water pipes. The scale formed at high temperature by the evaporation of water containing non-carbonate hardness is

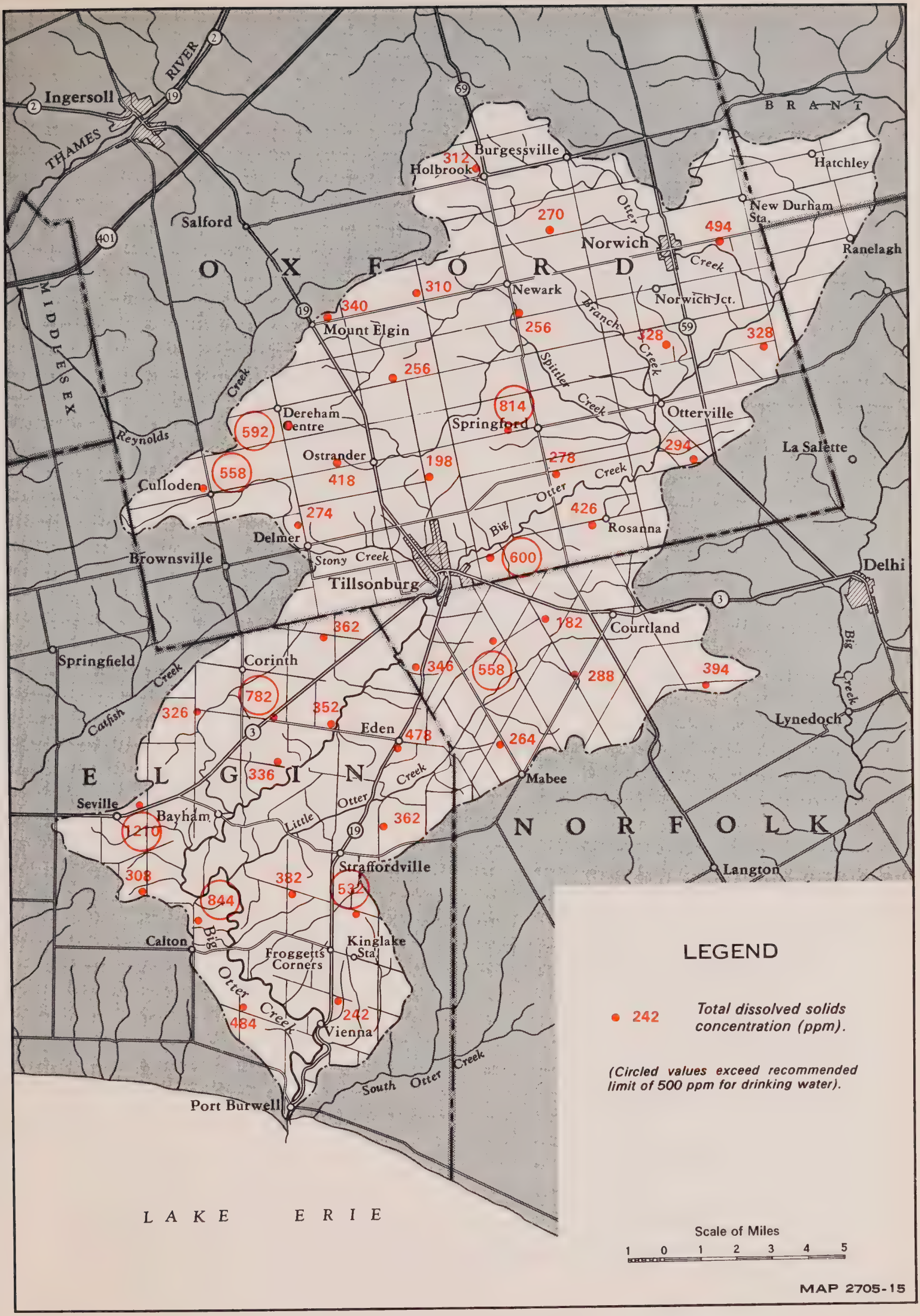


FIGURE 17 —Total dissolved solids concentration in representative overburden wells, Big Otter Creek basin.

tough, heat-resistant, and difficult to remove. In domestic uses, hard water can form scale in water heaters and radiators and requires excessive amounts of soap before a desired amount of lather is obtained. In the past the analysis for hardness was based on the reaction of the water with soap.

The total hardness of water is a measure of its calcium and magnesium content and can be represented by the following formula (Todd, 1959):

$$\text{Total hardness (as } CaCO_3) = 2.497Ca + 4.115\,Mg$$

where: Ca is expressed in ppm of Ca^{++}, and
Mg is expressed in ppm of Mg^{++}.

In Ontario the hardness of water may be classified as follows:

Total Hardness (ppm $CaCO_3$)	Classification
0 — 60	Soft
61 — 120	Moderately Hard
121 — 180	Hard
180 +	Very Hard

Figure 18 indicates the areal distribution of hardness in samples from overburden wells in the basin. Hardness values ranged from 50 ppm to 820 ppm. For the most part, ground water in the overburden is very hard and this hardness generally exceeds that of both bedrock- and surface-water samples.

Suitability of Water for Irrigation

An important use of water in the basin is for the irrigation of tobacco. Since the quality of irrigation water can affect the growth of plants, a check of the water quality should be made prior to its use for irrigation.

The characteristics of water that appear to be most important in determining its suitability for irrigation are:

(i) total concentration of dissolved salts,
(ii) the relative proportion of sodium to other cations,
(iii) the concentration of boron or other elements that may be toxic, and
(iv) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium.

The tolerance limits of tobacco for total salinity and boron are unknown, and consequently, the direct undesirable effects of irrigation water on tobacco plants cannot be assessed. However, the effects of the quality of irrigation water on the soil can be determined through numerous techniques.

Percentage of Sodium

The classification of irrigation waters with respect to the relative proportion of sodium to calcium and magnesium is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Loss of soil permeability occurs when sodium in solution is exchanged for the calcium and

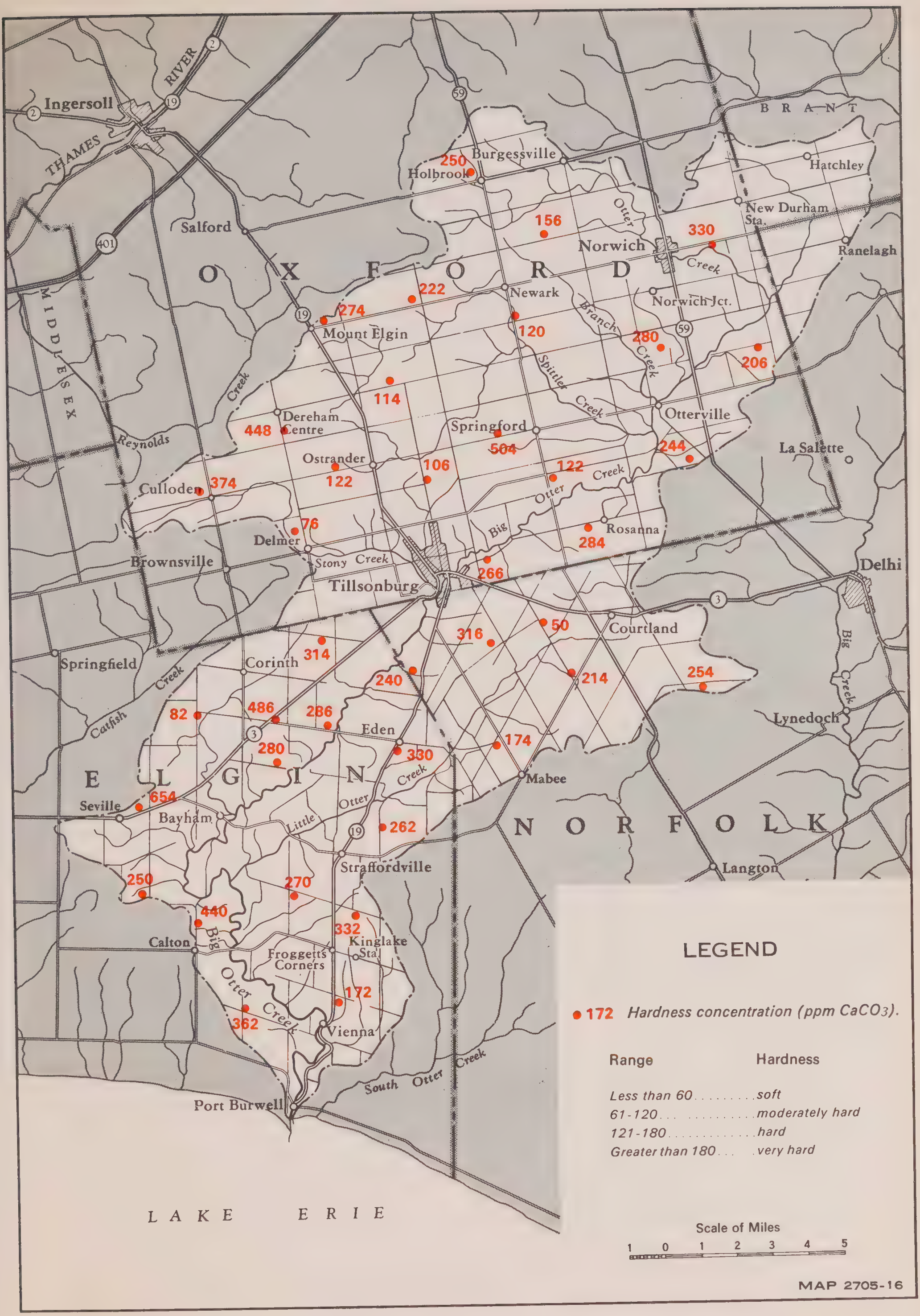


FIGURE 18 —Water hardness in representative overburden wells, Big Otter Creek basin.

magnesium adsorbed on fine soil particles. The exchange of sodium, from the water, for calcium and magnesium adsorbed on fine soil particles is referred to as "base exchange". The reaction

$$CaX_2 + 2Na^+ \rightleftharpoons 2NaX + Ca^{++}$$

(where X represents a unit of exchange capacity in solid-phase material) is reversible and governed by the law of mass action. As a result, accumulation of injurious salts in the soil can take place. Percentage of sodium is thus an important criterion for classifying irrigation waters and can be calculated from:

$$\%Na = \frac{Na^+}{Na^+ + K^+ + Ca^{++} + Mg^{++}} \times 100$$

where all ionic concentrations are expressed in epm.

Up to about 60% sodium, base exchange is ineffective because the divalent calcium and magnesium ions are adsorbed preferentially by the clay particles of the soil. In waters in which the per cent sodium value is greater than 60%, the preferential adsorption of divalent cations by soils is overcome. Figure 19 indicates that there are four bedrock wells and three overburden wells where the water contains more than 60% sodium; these waters as classed as "doubtful" for irrigation. All other bedrock and overburden well waters sampled are "excellent" to "permissible" for irrigation.

A classification of irrigation waters utilizing percentage of sodium and water conductivity is shown in Figure 20. According to this approach, samples from three bedrock wells, all located in the southern portion of the basin, were "permissible to doubtful" and samples from six overburden wells plotted in the "good to permissible" class. All other overburden and bedrock wells sampled had water of good to excellent quality for irrigation.

Residual Sodium Carbonate

Residual sodium carbonate (RSC), an indirect measure of the sodium hazard, represents the excess of carbonate plus bicarbonate concentration over the calcium plus magnesium concentration, where the concentrations are expressed in epm. Black-alkali soils may result when evapotranspiration draws water from the soil, leaving a residual concentration of salts in water. Consequently, calcium-magnesium carbonate or bicarbonate may precipitate and leave an excess of bicarbonate ion which in combination with sodium may be harmful to soil structure.

Suitability of water for irrigation, on the basis of RSC, is shown below:

RSC	Suitability for Irrigation
less than 1.25 epm	Safe
1.25 — 2.50 epm	Marginal
more than 2.50 epm	Unsuitable

where $RSC = (CO_3^{--} + HCO_3^-) - (Ca^{++} + Mg^{++})$.

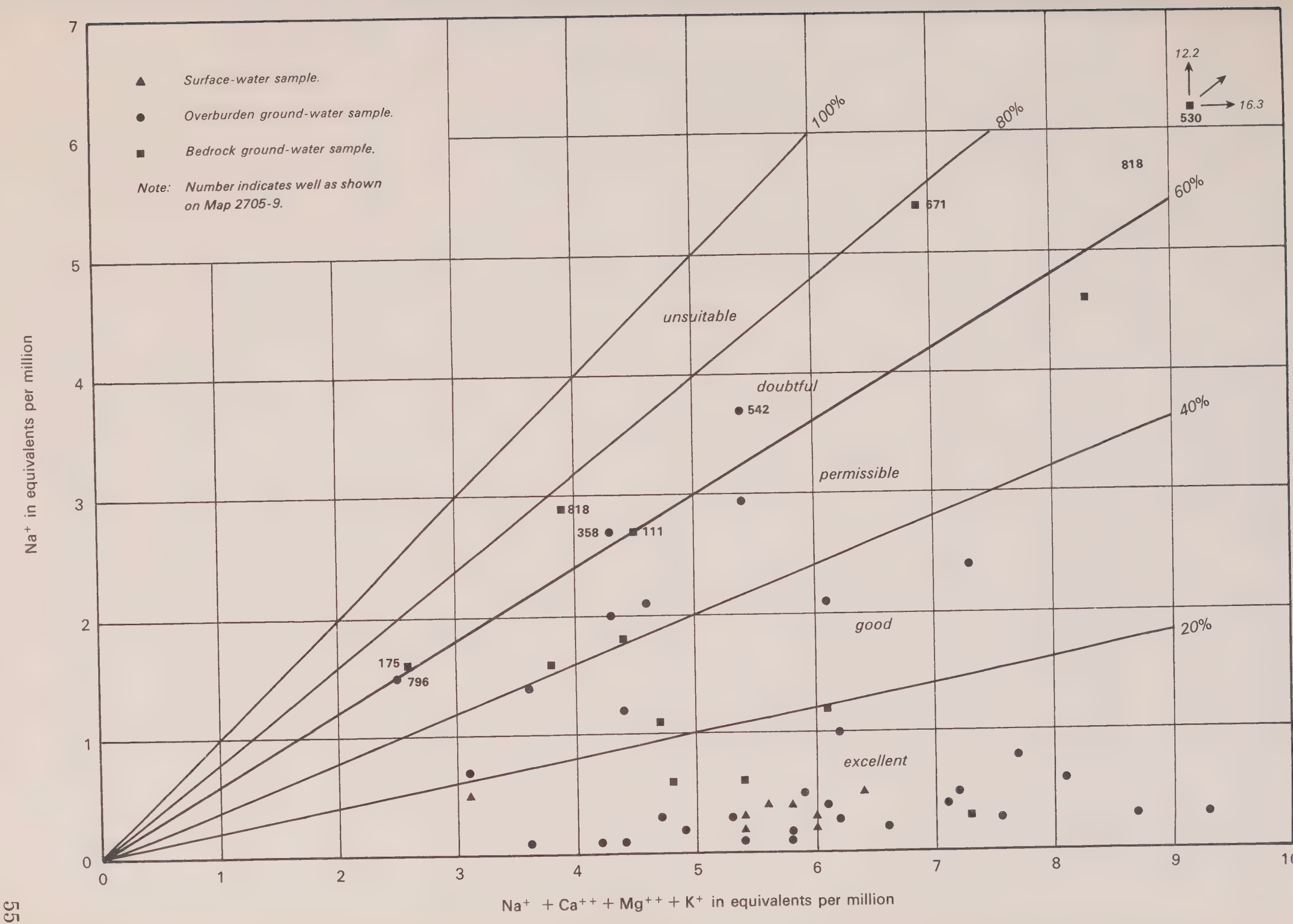


FIGURE 19 – Suitability of water for irrigation, classified on the basis of percentage of sodium, Big Otter Creek basin.

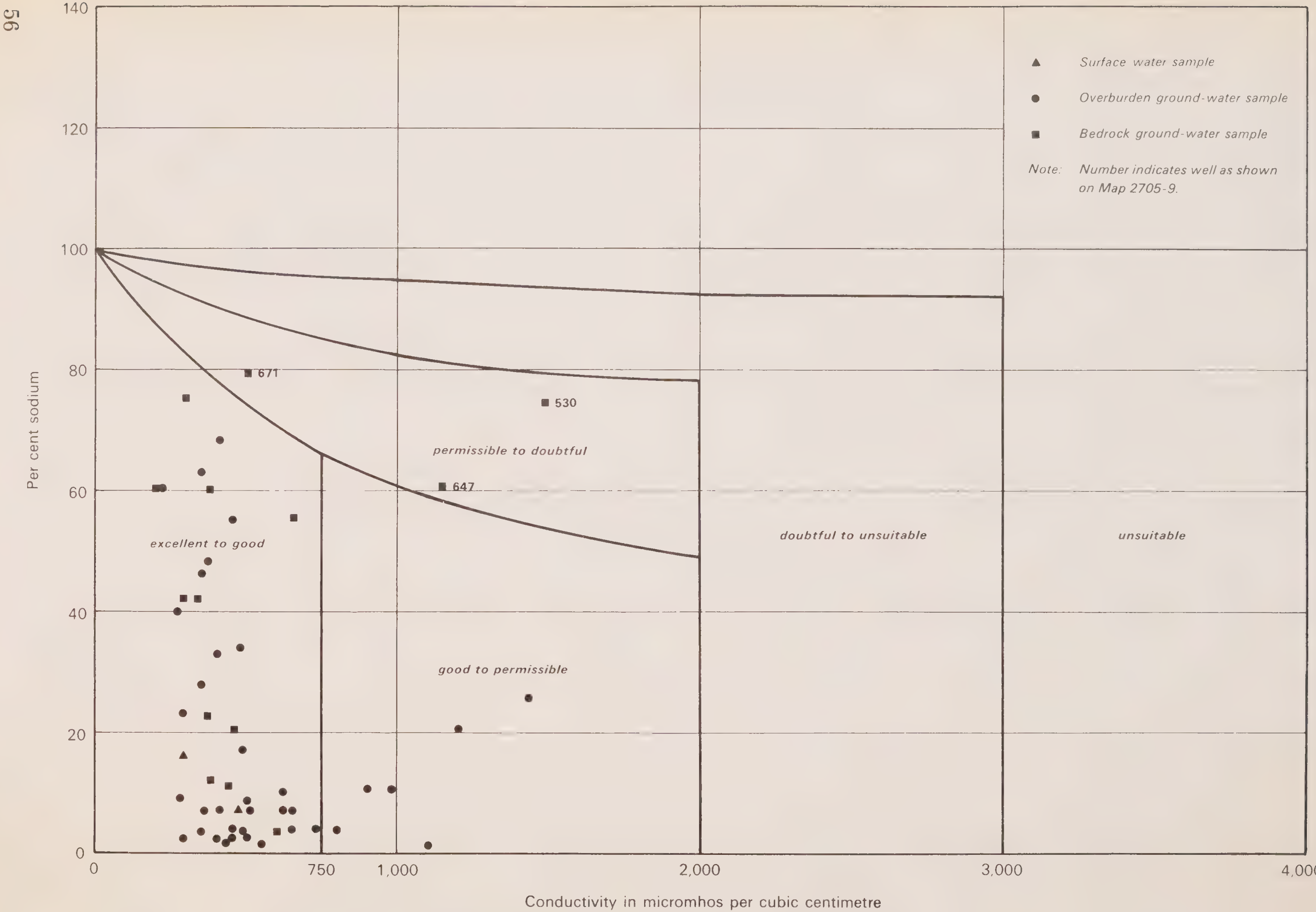


FIGURE 20 – Suitability of water for irrigation, classified on the basis of percentage of sodium and conductivity, Big Otter Creek basin (after Wilcox, 1948).

Figure 21 is a graphical representation of the RSC values of water samples in the basin. Samples from one bedrock-well and one overburden-well are classified as "unsuitable"; samples from three other overburden wells and four bedrock wells plot in the "marginal" range. All other sampled well-waters are classified as safe for irrigation purposes.

Sodium Adsorption Ratio

The direction in which the base-exchange reaction proceeds depends on the concentration of sodium in relation to calcium and magnesium. The sodium to calcium and magnesium ratio is termed the "Sodium Adsorption Ratio" (SAR). The mathematical expression of SAR for irrigation waters is:

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\dfrac{\mathrm{CA}^{++} + \mathrm{Mg}^{++}}{2}}}$$

where all concentration values are expressed in epm.

A relationship between SAR of irrigation waters and exchangeable sodium in the soil has been demonstrated (Hem. 1959). Hence, the SAR values can be used as an indirect expression of the tendency of irrigation waters to enter into base-exchange reactions in the soils.

In evaluating water for irrigation, the sodium hazard may be expressed as SAR and the salinity hazard as electrical conductivity. Figure 22 depicts the SAR — conductivity relationships found in the waters of the Big Otter Creek basin. The salinity hazard classification for irrigation waters is quoted as follows (U.S. Salinity Lab. Staff, 1954):

C1 — Low-salinity water can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

C2 — Medium-salinity water can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

C3 — High-salinity water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

C4 — Very high salinity water is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

The SAR reflects the sodium hazard and the classification is quoted as follows (U.S. Salinity Lab. Staff, 1954):

S1 — Low-sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops may accumulate injurious concentrations of sodium.

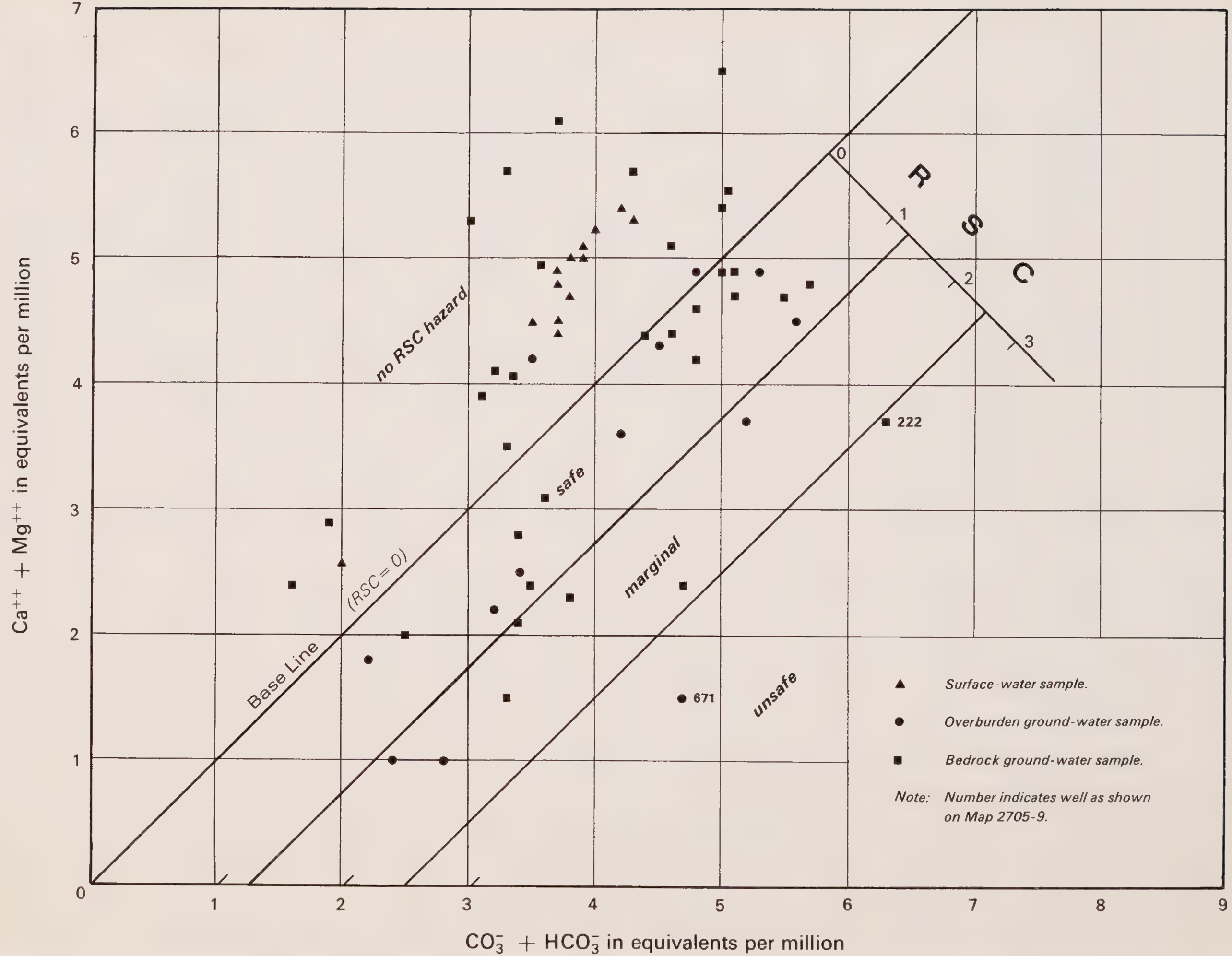


FIGURE 21 — Suitability of water for irrigation, classified on the basis of Residual Sodium Carbonate (RSC), Big Otter Creek basin.

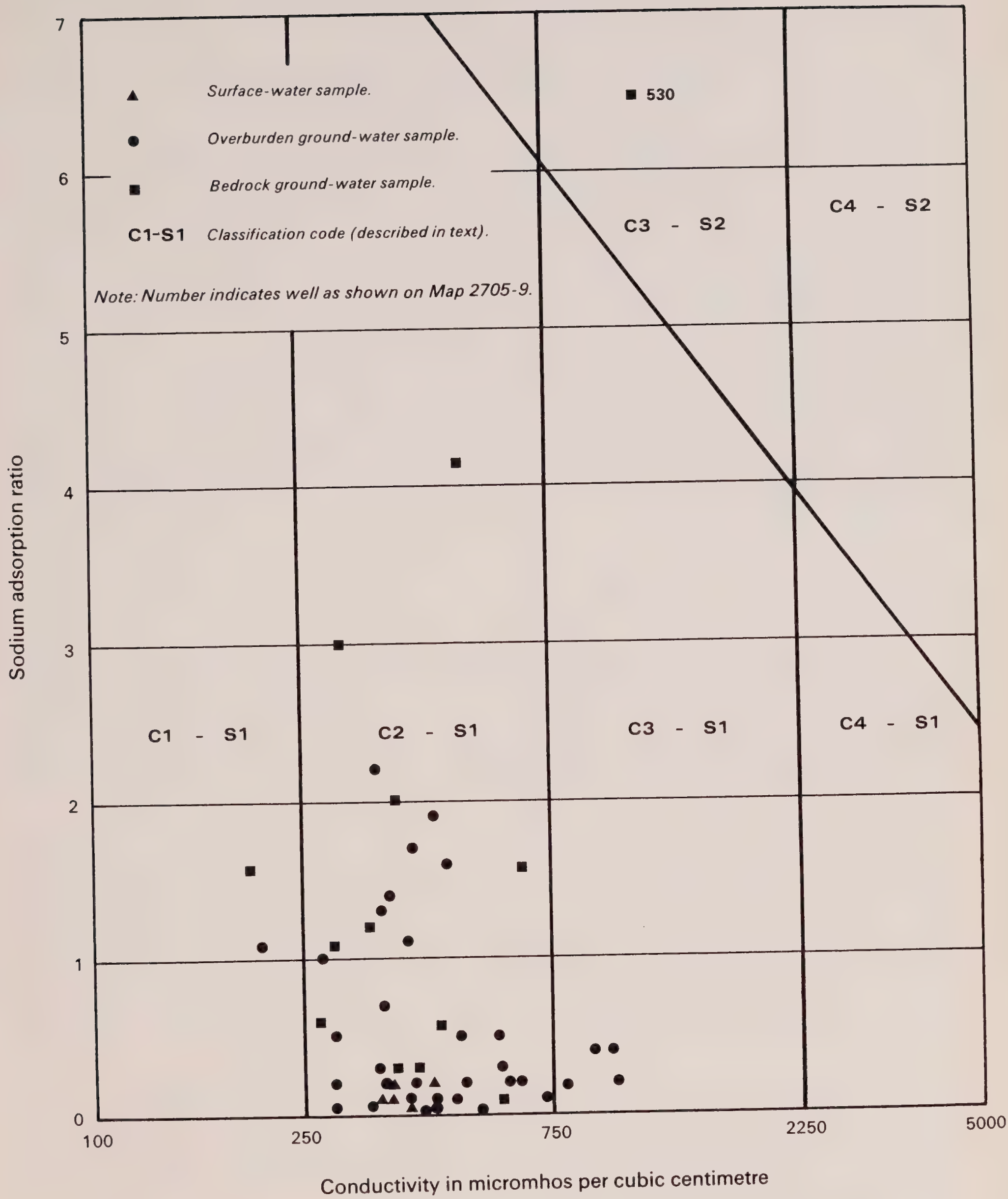


FIGURE 22 — Suitability of water for irrigation, classified on the basis of sodium and salinity hazards, Big Otter Creek basin (after U.S. Salinity Lab. Staff, 1954).

S2 — Medium-sodium water will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

S3 — High-sodium water may produce harmful levels of exchangeable sodium in most soils and will require special management — good-drainage, high leaching, and organic matter additions.

S4 — Very high sodium water is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

In the Big Otter Creek basin only one bedrock well sample is rated C3-S2 (well 530). One bedrock well and four overburden well samples fall in the C3-S1 category. The majority of samples from wells are grouped in the C2-S1 class of medium-salinity and low sodium-hazard water.

In the basin, SAR (sodium hazard) does not have as strong an influence on the classification of the water samples as does the electrical conductivity (salinity hazard). The wide range of conductivities varies the salinity hazard from class C1 to class C3, whereas the SAR values (except for one sample) limit the sodium hazard to the S1 class. Consequently, the greater hazard to be encountered in the irrigation waters of the basin is the high mineralization of ground water.

Summary

Most of the waters in the basin area are of the calcium-magnesium bicarbonate type (Figure 23). In the overburden, the magnesium-bicarbonate waters are found primarily in the northern end of the basin; calcium-bicarbonate waters dominate the southern part. Waters derived from rock wells are mainly of calcium-magnesium bicarbonate or sodium-bicarbonate classification. All surface-water samples are classified as calcium-bicarbonate waters.

Except for a few particular aspects of water quality on a local scale, the general quality of water, from all sources, for domestic and stock purposes is good. Some of the bedrock wells in the southern portion of the basin contain salty water; however, the extent of these wells is limited. The only other hazard to human health would be the high nitrogen content that was found to exist in two wells; care must be taken in their use. Although iron concentrations in many wells in the basin were found to be above the recommended limit of 0.3 ppm, this element, when present in large concentrations, is more a nuisance and inconvenience in domestic use rather than a health hazard.

The bedrock waters, due to their generally higher sodium hazard, are less fit for irrigation than the overburden or surface waters. On the basis of sodium- and salinity-hazards, all surface and most ground waters are acceptable for irrigation. The bedrock ground waters at the extreme southern portions of the basin are unsuitable for irrigation.

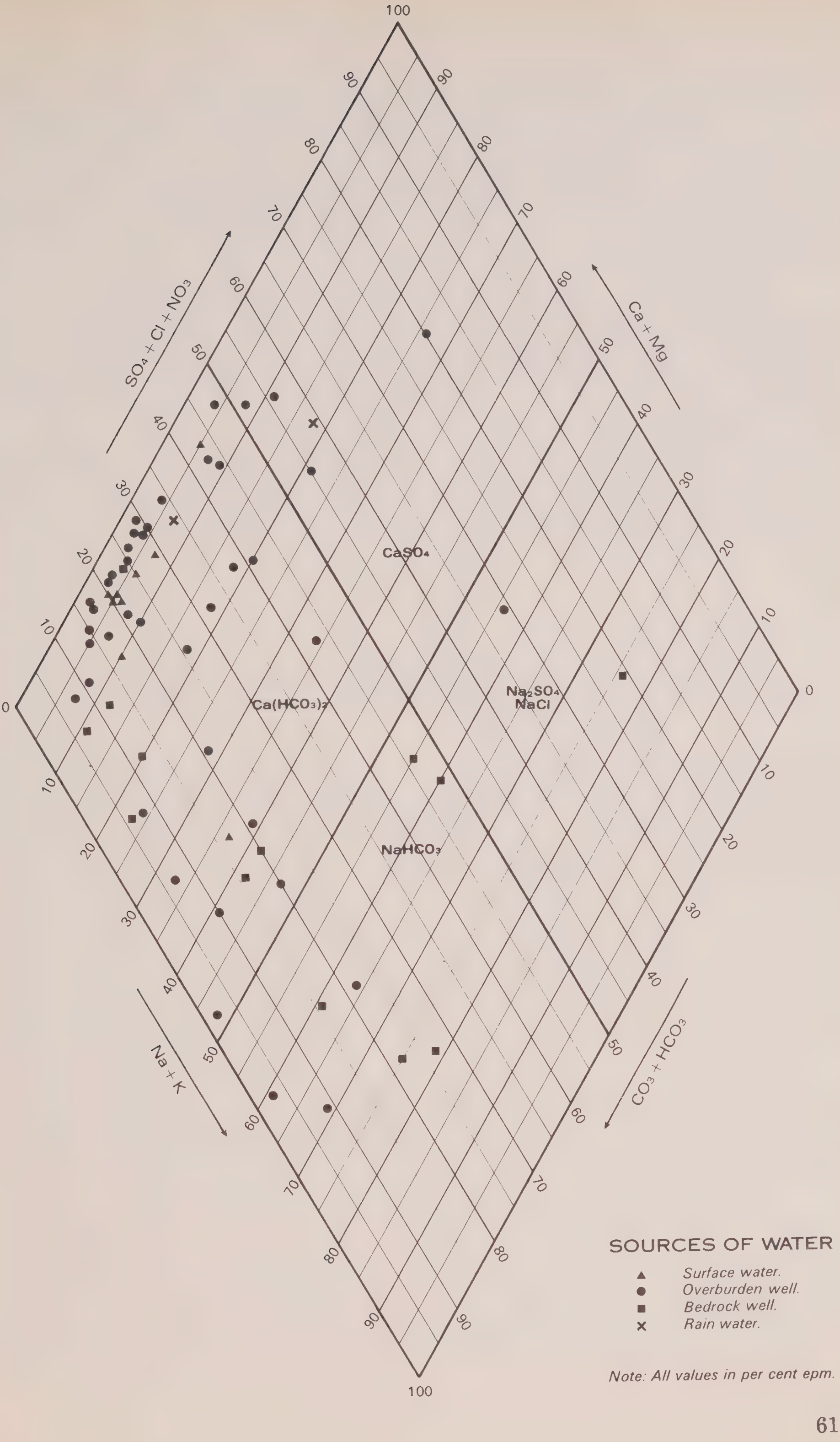


FIGURE 23 – Composition of waters, Big Otter Creek basin.

WATER-RESOURCES DEVELOPMENT

Surface Water

Surface water is a resource that can be utilized as a water supply, as a means of waste dilution and assimilation, for cooling or air conditioning, for recreation, or for its aesthetic value. Unfortunately, using surface water for one purpose may not be compatible with its use for some other purpose. For example, if stream water is used for industrial cooling it may become unfavourable for trout, primarily a cold-water fish.

Surface-water development depends upon the amount and distribution of water available, the runoff pattern, and the physical characteristics of the basin.

The relative distribution of water in the below-normal precipitation water year of 1964-65 is shown by the following budget equation:

$$P(30.81) = R(15.10) + ET(15.71)$$

where P = precipitation
R = runoff
ET = evapotranspiration + all other changes

All values are in inches

The lowest precipitation on record at Delhi is 26.6 inches for the calendar year 1941. Runoff for that year would be disproportionately lower because of the higher evapotranspiration opportunity. At present there is no way of controlling the precipitation pattern but if this should ever become possible, one of the most important considerations must be the benefits and hazards relating to other items of the budget equation and the stream runoff characteristics.

Evapotranspiration in the basin represents consumptive use of water by plants, most of which are beneficial. This item of the budget equation can be increased at the expense of runoff merely by diverting stream flow for irrigation. This increases the actual evapotranspiration to a level closer to the potential evapotranspiration, which was calculated to be 23.37 inches for the water year ending in 1965. It is much more difficult to increase runoff by reducing evapotranspiration.

The runoff pattern, which represents the response of the basin to precipitation, is so clearly dominated by the precipitation pattern that other natural controls are not easily recognized (Figures 7a and 7b). However, both high and low flows are influenced by infiltration and seepage and these in turn are related to the geology of the surficial deposits.

The 15.1 inches of runoff at Vienna for water year 1964-65 represents 138,000 acre-feet (37.6 billion gallons), an average of about 805 acre-feet (218.4 million gallons) per square mile. Because of the wide variation in runoff characteristics, it would be a grave error to assume this average can be applied indiscriminately over the whole basin. For example, the basin of Little Otter Creek is underlain almost entirely by sand and the total runoff from this area was 17.0 inches for water year 1964-65 (Canada Dept. of Energy, Mines and

Resources, 1967). Consequently, the runoff from some areas in other parts of the basin must have been less than the 15.1-inch average for the entire basin.

A dam can be operated to serve many purposes in surface-water management. The storage reservoir created by a dam can be used to alter the runoff pattern of the stream by reducing high flows and augmenting low flows. Unfortunately, serious conflicts for the use of stored water can arise in times of drought. Irrigators require water that may also be needed for waste dilution or natural stream functions. Also, release of water from a reservoir reduces its recreational value although increasing its flood control capability.

Lacustrine clay and clay till can provide a good impermeable base for dams whereas reservoirs on the surficial sand may be subject to high seepage losses and foundation failure by piping. The Otter Creek Conservation Report describes the best reservoir sites in the basin (Ontario Dept. of Lands and Forests, 1962).

The areas most susceptible to flooding are along Big Otter Creek and its tributaries, particularly the lowlands just below Tillsonburg (Ontario Dept. of Lands and Forests, 1962). Any part of a stream valley underlain by stream alluvium should be regarded as subject to flood hazards, unless it is part of a raised terrace. The flood hazard at any point can be estimated by relating the peak flows, at the point, to flood stage by means of a stage-discharge curve.

Ground Water

Ground water has a worth far beyond its normal market value because it is the only economic source of water for most rural users. Even for large municipal and industrial supplies, ground water may be the best source; however, surface-water potential is easier to evaluate and for this reason is preferred in many cases.

Ground water is considered to be water temporarily stored below the land surface and is constantly in slow movement towards a natural discharge area. Some of this flow may be diverted toward wells, but unless this causes either reduced natural discharge or increased natural recharge, the water from wells must come from ground-water storage, a fact recorded by lower water levels in wells. Under present conditions, ground-water withdrawal in the basin is unlikely to cause significant changes in the hydrologic regimen, other than local lowering of the piezometric surface.

Ground-water development requires finding and exploiting an aquifer. In the Big Otter Creek basin, most water-well drilling is successful in this regard. Where drilling is unsuccessful, i.e., well failures occur, an understanding of the local occurrence and distribution of ground water is necessary to attempt a solution of the problems in the area.

The occurrence of ground water depends solely on the distribution of geologic units, which may be classified broadly as "aquifers" and "aquitards". An aquifer is any overburden or rock unit that is permeable enough to yield useful quantities of water to a well, whereas an aquitard will not. In the Big Otter Creek basin, the main aquifers are limestone and the coarse, sorted sand and gravel deposits of the overburden. The availability of ground water is shown on map 2705-5.

Water-well records show that water may be obtained anywhere in the basin from wells in bedrock but only in the northern half of the basin is the bedrock water generally fresh. Even there, the fresh water is restricted to the upper zone of the bedrock and deep wells will encounter mineralized water which is not of economic value at present.

Ground-water occurrence in the overburden is interpreted from the surficial geology and from available water-well records. Map 2705-1 shows the type and distribution of wells in the basin. Three cross-sections in the basin, drawn from water-well information, show in general the distribution of aquifers (Figure 24). Many wells are not located right on the line of section and so appear to be too high or too low when projected onto the section. The drillers logs of all wells used in the sections and all wells mentioned in this discussion are reproduced in Appendix A.

On the basis of availability of ground water, the basin can be divided into north and south halves (Map 2705-5). Generally, well yields in the northern portion are better than those in the southern half. The surface sand of the Norfolk Sand Plain is permeable and thick enough in most places to provide adequate domestic supplies to well points. This in part accounts for the favourable ground-water conditions in the lowlands adjacent to the upper half of Big Otter Creek. Wells 101, 199, 213, and 832 are single or multiple well points that provide up to 300 gpm (gallons per minute). Out of the lowlands, surface sand becomes thinner and is generally less productive.

South of Tillsonburg the sand becomes finer grained and consequently less permeable but well points are a common source of water here as well. At scattered locations in the more favourable area shown south of Courtland, very productive well-point systems have been installed (wells 874, 712, and 708). Throughout most of the southern half of the basin shallow wells produce less than 10 gpm. The surface sand deposits along the western side of the basin are apparently too thin to be good aquifers. The relatively productive well points near Corinth are not completed in surface sand but in sand below a clay horizon in the lacustrine sediments (well 589). The presence of clay strata is to be expected in lacustrine deposits like this and even where the aquifer is well developed, a local variation in the composition of the deposit may be responsible for some failures to develop a successful well.

The distribution of the buried aquifers in the overburden is not evident from the map of surficial deposits, but is illustrated by means of cross-sections. Cross-sections A-A′ and B-B′ (on Figure 24) illustrate that over most of the northern half of the basin, wells are successful in the overburden. Section A-A′ shows that west of Norwich, the St. Thomas and Norwich end moraines and the intervening till plain are underlain by unproductive till, but many wells penetrate this till and derive water from sand and gravel aquifers encountered at an elevation of about 850 feet. East of Norwich, the surficial sand forms a thin blanket over the till; locally it is thick enough to be a good aquifer (well 127).

Section B-B′ is rather similar. The Tillsonburg moraine is underlain by clay till, but thick sand and gravel beds occur at depth in some wells and large quantities of water can be developed from such aquifers (wells 395 and 396). Many wells in this area are successfully completed at depths that vary from 50 to 100 feet. Near Tillsonburg and eastward, the cross-section shows the blanket of lacustrine sand to be much thicker than to the north, and it is extensively developed as an aquifer. Near Courtland the sand thins against the flanks of the "Paris moraine".

The overburden thickens towards the south because the bedrock surface has a greater slope than the present land surface (maps 2705-2 and 2705-4). Cross-section C-C′ indicates that the composition of the overburden also changes. The proportion of sand and gravel strata decreases markedly and even thin aquifers are lacking in some places, likely because this was an area of deeper water during the earlier glacial-lake stages. Sediments deposited here were

mostly fine grained. Thin surface sands are generally well drained near the deep valleys but provide small quantities of water to dug wells on much of the uplands region. Many springs, formed at the contact between sand and underlying clay, exist along the valley slopes and in particular in the Little Otter Creek valley. These "contact" springs are developed for the Vienna water supply and many individual domestic users.

The response of an aquifer to pumping depends on its thickness, permeability, and lateral extent. The permeability of an aquifer can be determined from analysis of pumping tests, and the lateral extent of surface aquifers from field mapping. However, for deeper aquifers in the overburden, the existing information is inadequate for determining the continuity of aquifers indicated by different wells. Consequently, a buried aquifer must be located, or its presence must be confirmed, by drilling, and its boundary conditions determined from pump-test data. Well failures in the overburden can occur due to the absence of an aquifer in the section, the failure of the driller to recognize the presence of the aquifer, or the failure of the driller to develop a successful well in the aquifer after it has been found.

One of the most efficient ways of developing large supplies of ground water is by induced infiltration. This method requires an aquifer in direct hydraulic contact with a body of surface water such as a stream or a lake. Ground water pumped from the recharged aquifer is replaced by infiltration from the surface-water source. The Recent alluvium along Big Otter Creek and its tributaries does not seem sufficiently extensive and permeable for large-scale induced infiltration; however, favourable conditions may occur locally where a stream flows over sand and gravel. This possibility warrants investigation wherever small supplies (30-50 gpm) will meet the need. The cross-sections reveal that the channels of the larger streams are mostly in till or lacustrine clay, and are therefore generally unfavourable for induced infiltration.

Waste Disposal

Disposal of municipal and domestic sewage and fluid industrial wastes can be a serious problem in the basin (Ontario Water Resources Commission, 1959, 1963). Generally sewage is disposed of as septic tank effluent or untreated waste into the ground or into the streams. The low flows encountered in streams may not be sufficient to dilute and assimilate such wastes and this situation can be aggravated by irrigation withdrawals during the low-flow period. Any comprehensive plan for water-resources development must include consideration of this conflict of interest in water use.

Domestic septic tank systems can probably be satisfactorily utilized in rural areas and hamlets where the drainage is good; however, large-scale developments using this kind of system should be discouraged under all soil conditions. In areas underlain by till or lacustrine clay, each site should be checked for adequate drainage conditions. In porous soils, septic tank systems should not be placed close to the water-table, although any subsurface pollution caused by septic tank effluent is likely to be restricted to the vicinity of the tank and drainage field.

The Town of Tillsonburg is the only community in the basin that has a sewage-treatment plant. The secondary-treatment plant effluent discharged into Big Otter Creek at Tillsonburg averaged 0.612 million gallons per day (mgd) in 1965 and 0.731 mgd in 1966. The capacity of the treatment plant is to be increased in the near future from 0.67 to 1.80 mgd.

Waste disposal into deep bedrock formations is not practised at present in the Big Otter Creek basin. Evaluation of any proposals for waste disposal into such formations should include an awareness that fluids introduced into the ground-water flow system can be expected to reappear at the surface sometime in the future!

Present Water Use

Methods of Water Extraction

A variety of techniques and well construction methods are used to extract ground and surface water for domestic, stock, industrial, municipal and irrigation uses in the Big Otter Creek watershed. The economic factors and convenience of water extraction determines whether a ground- or surface-water source is used. Three main types of extraction are used throughout the basin: wells, ponds and streams.

In general, the type of geologic deposit and the amount of water required for a specific purpose dictates the method of ground-water extraction. A well can be dug, bored, drilled, driven or jetted as a sand point, or in some cases be constructed through a combination of these methods.

Three main types of ponds are common in the basin: on-stream, off-stream and dugout. An on-stream pond, where the bottom or sides have been enlarged to allow for greater storage, or where storage on the stream has been created through a dam, supplies water directly from a stream. An off-stream pond is supplied by the stream through a bypass ditch or canal. A dugout pond is an excavation below the water-table and is usually in a sandy soil where the water-table is a few feet below the ground surface and where the rate of ground-water discharge into the pond sustains the supply.

"Stream takings" of water are direct with little or no modification to the stream. Usually water is extracted from deep ponds in the stream where the volume of surface water storage is large.

Figure 25 is a graphical representation of the number of extractions from wells, ponds and streams for specific purposes of domestic, stock, irrigation and industrial use. Most wells serve domestic and stock needs; ponds and streams supply water exclusively for irrigation and stock.

Domestic and Stock Use

The use of water for rural domestic and stock purposes comprises 36 per cent of the total water consumption in the drainage basin. Figure 25 indicates that water extracted for domestic use is through dug, drilled, and sand-point wells. Sand points are successful only in areas where the saturated sand is thick enough to produce sufficient quantities of potable water.

In the drainage basin, dug wells for domestic purposes are confined mostly to areas of clay till and where the water-table is high. The success of these dug wells depends upon slight local variations in transmissibility of the till.

People in small communities depend on drilled wells, sand points, and dug wells for their water supply.

The average per capita domestic consumption in the basin was assumed to be 50 gallons per day. At this rate the annual, rural, water consumption is 206,000,000 gallons or 21 per cent of the total water consumption in the area.

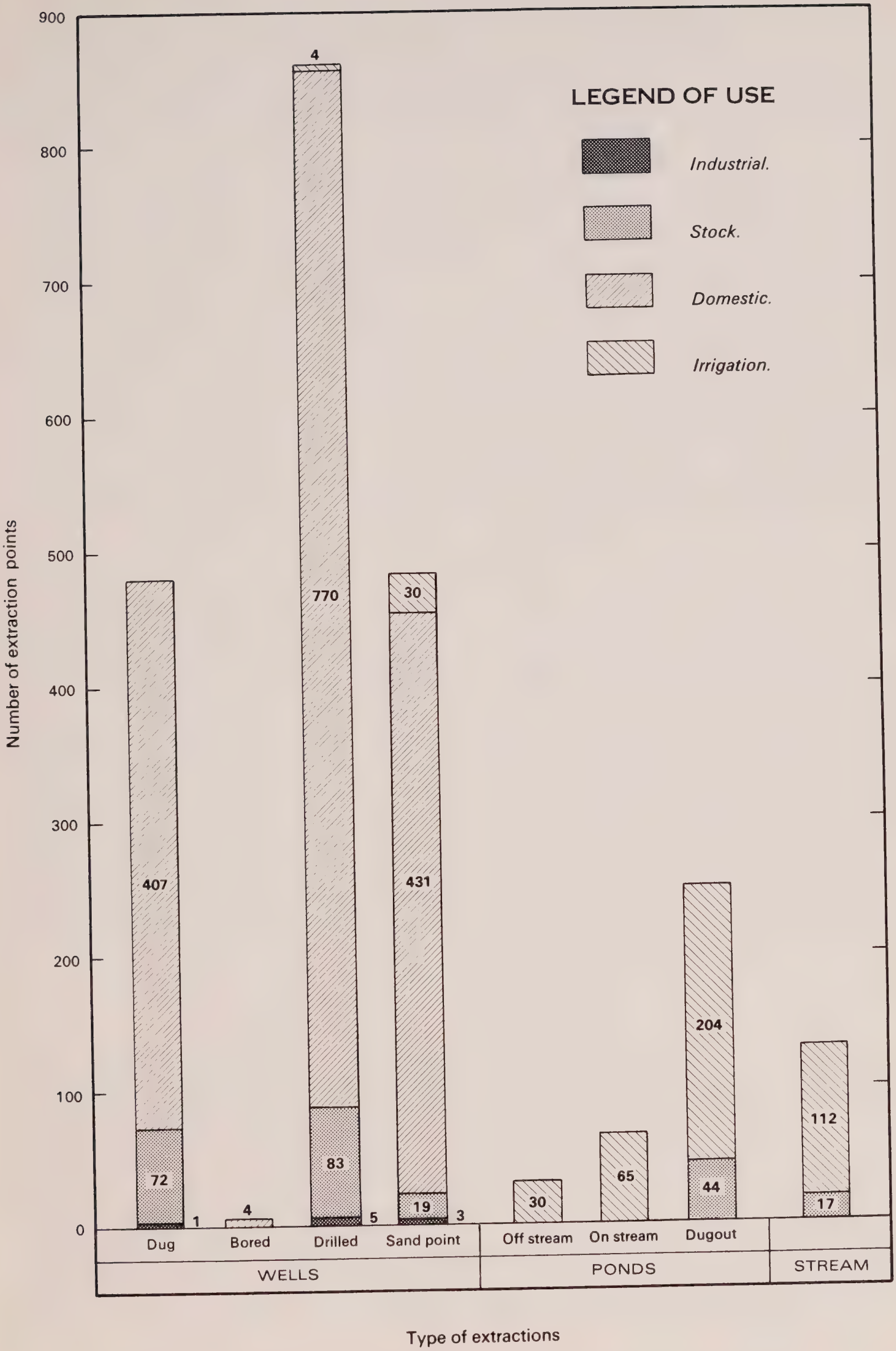


FIGURE 25 — Uses and sources of water in the Big Otter Creek basin.

Domestic consumption by small communities makes up 7 per cent of the total, or 65,000,000 gallons per year.

Water for stock is extracted mainly from dugout ponds, wells and streams. In calculating the consumption of water by livestock, the following values were used:

Livestock	Amount
Each producing milk cow	30 gals/day
Each beef cow	12 gals/day
Each horse	12 gals/day
Each hog	1.5 gals/day
Each sheep	1.5 gals/day
Each 100 chickens	5 gals/day
Each 100 turkeys	10 gals/day

The total stock-water consumption is approximately 149,000,000 gallons per year or 15 per cent of the total water used in the drainage basin.

Municipal and Industrial Use

In the course of the extensive farm survey conducted during the summer of 1965, it became apparent that only a few small industries were not served by municipal water systems. Hence, individual industrial uses of water were not detailed but were included in the municipal consumption figures.

Norwich, Tillsonburg, and Otterville have municipal water systems with ground-water sources of supply. The villages of Port Burwell and Vienna have been searching for sufficient ground-water supplies to satisfy their municipal needs but so far have been unsuccessful.

The total amount of water extracted by Norwich and Tillsonburg in 1965 was 284,000,000 gallons which is 29 per cent of the total water used in the basin. No figures are available for pumpage at Otterville. Figure 26 indicates the population of Tillsonburg and the total annual water extraction from five drilled wells for the period 1951-1965.

Irrigation Use

Irrigation of tobacco accounts for 28 per cent of the total water use in the basin, or about 280,000,000 gallons per irrigation season. In the administrative procedures of the Ontario Water Resources Commission in issuing permits to take water for irrigation, the maximum rate approved provides for sufficient water to satisfy maximum estimated crop needs. Lower rates of taking may be specified to protect the natural functions of the stream and provide water for downstream users. The amount of water used for irrigation was estimated on the basis that about 50 per cent of the daily volume allowed by the permits is actually used by irrigators for an average of seven irrigation days. The locations of water takings authorized by permits issued by the Ontario Water Resources Commission are shown on Map 2705-6.

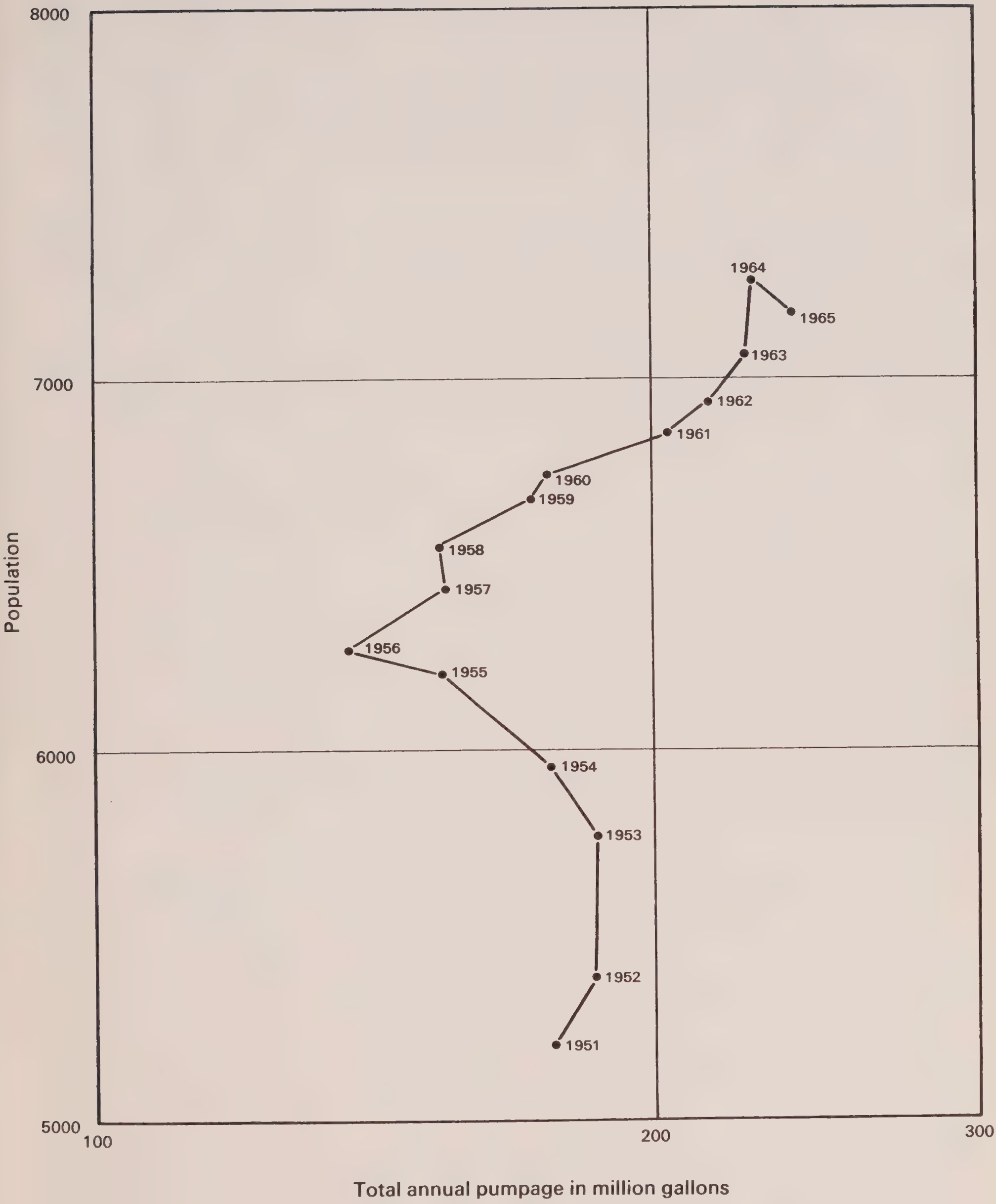


FIGURE 26 — Population and total pumpage at Tillsonburg, Ontario.

Tobacco growing is limited to sandy soil and this accounts for the distribution of planted acreage of tobacco, in 1965, shown below:

Township	Acreage
Bayham	2395 acres
Dereham	314 acres
Malahide	432 acres
Middleton	1612 acres
South Norwich	2576 acres

Other crops such as potatoes and grain are irrigated sporadically. The exact acreages and the amount of water used are unknown, but are assumed to be relatively small and were not included in the estimates of water for irrigation use.

Five main methods of water extraction for irrigation are used: dugout ponds, on-stream ponds, off-stream ponds, direct stream takings, and well-point systems or wells. The relative percentage of each method of extraction for irrigation purposes is given below:

Method of Extraction	% of Total Number of Extractions
Dugout pond	45
Off-stream pond	7
On-stream pond	15
Stream taking	25
Well-point system or drilled well	8

Summary of Uses

The following is a summary of the estimated amounts of water extracted for the various uses in the basin:

Type of Use	Amount (gallons per year)	% of Total Water Use
Irrigation	280,000,000	28
Livestock	149,000,000	15
Municipal systems	284,000,000	29
Rural domestic	206,000,000	21
Small community domestic	65,000,000	7
Total	984,000,000	100

Of the three broad types of water use (irrigation, municipal, and domestic and stock) in the basin, the domestic and stock use is the largest — 43 per cent (420 million gallons) of the total use of water; irrigation and municipal uses are almost of equal percentage — 28 per cent (280 million gallons) and 29 per cent (284 million gallons) respectively. In the examination of the above figures,

the important consideration is the fact that the areas of water demand for domestic and stock use are relatively evenly distributed throughout the basin, but the heavy municipal and irrigation withdrawals are concentrated in specific parts of the watershed. Consequently, it is within the local areas of concentrated withdrawals that ground- and surface-water supplies can be overtaxed and problems such as inadequate waste dilution and assimilation and reduced crop yields can occur. These problems are presently not prominent in the Big Otter Creek basin; however, the conservation of ground- and surface-water resources must be realized if adequate supplies of fresh water are to be available to meet increasing demands and prevent shortages during drought periods.

SUMMARY AND CONCLUSIONS

A water-resources survey was carried out in the Big Otter Creek basin to evaluate the resource in terms of occurrence, distribution, quantity and quality for the purpose of providing guidance for its development and conservation. During the course of the one-year study it became evident that much of the quantitative data necessary for a detailed water-resources evaluation was not available and could not be obtained in one field season. This report presents the results of the investigation and a general evaluation of surface- and ground-water conditions based on the data available.

The conducive conditions of temperate climate and sandy soil have made the area a prime tobacco-growing region. The desire to ensure or increase yields per unit area has brought about an increase in irrigation of the tobacco crop to overcome any seasonal deficiency of soil moisture. The resulting demand for surface and ground waters has led to increased competition for water throughout the basin. Consequently, water-resources evaluation in the basin has special importance to those who depend on the resource for their livelihood.

Much of the basin is covered by surface-sand deposits which are poorly drained in flat regions of the basin and well drained adjacent to the deeper stream valleys. In areas of high water-table in the sand, shallow dugout ponds provide adequate supplies of water for irrigation and shallow dug wells and well points are commonly used to provide water for most domestic and stock uses. Where the saturated surface sand is not thick enough, wells drilled deeper into the overburden are usually successful, particularly in the northern regions of the basin. The surface till located in the northern part of the basin is usually of low productivity; however, the till cap is thin in many places and dug or drilled wells derive water out of underlying sand deposits (as indicated in Figure 24). The hydrogeologic conditions in the southern part of the basin are such that the productivity of most deep overburden formations is low and decreases towards Lake Erie. In this part of the basin the surface sands, where sufficient saturated thicknesses occur, are the best sources of ground water for wells. Where water from these sources is inadequate, the development of existing surface-water sources is the main economic alternative.

Natural recharge of water through permeable overburden materials to porous bedrock formations is common and water-bearing zones are present throughout the bedrock in the basin. The most notable source of water from the bedrock is within the top few feet of the bedrock surface. In the majority of cases this zone can supply quantities of water sufficient for domestic and stock uses; however, the quality of this water in the southern part of the basin is poor (see Map 2705-9) and therefore renders it unsuitable or marginal as a domestic or irrigation supply. Bedrock sources of water in about the northern two-thirds of the basin seem to be generally of satisfactory quantity and quality for domestic, stock and other moderate-volume uses.

Big Otter Creek and its main tributary, Little Otter Creek, are "consequent" streams that have had the formation of their channels controlled by the adjacent Tillsonburg and "Paris" morainic ridges. Near the deep valleys of Big Otter Creek and its larger tributaries, drainage of surface sands is generally good.

However, short distances from the valleys in flat, sand, till or clay areas where stream dissection is small, bogs and swamps exist. Improved land drainage has been successful in some areas but unsuccessful in other regions where sufficient gradients could not be obtained or maintained in the drainage systems. The improved drainage patterns and areas of improved drainage are shown on Map 2705-8.

Except for the man-made reservoirs at Norwich, Otterville and Tillsonburg, there are no large open bodies of water in the basin. Therefore, surface-water resources in the basin are mainly dependent on the natural flows and storage capacities of the streams. Lake Erie contains a potential source of supply and may be utilized as the demand for water in certain areas cannot be met from local sources.

The highest streamflow conditions in Big Otter and Little Otter creeks are generally recorded during the spring months of March and April; the lowest flows in the summer and fall. The flow-duration curve indicates that 50 per cent of the time the flow in Big Otter Creek at Vienna exceeded 190 cfs.

Of particular interest in the evaluation of surface-water resources are the low-flow conditions of Big Otter Creek and its larger tributaries. At Vienna, the lowest average annual seven-day minimum flow has been approximately 13 cfs. It is estimated statistically that the seven-day minimum flows at Vienna will be less than 27 cfs on an average of one year in ten years and less than 53 cfs on an average of five years in ten years. Minimum flow conditions in streams north of Vienna are indicated on Figure 11.

Flood-flow conditions are shown in Figure 12. The maximum flood at Vienna was recorded as 6400 cfs on March 6, 1965, and this flow has an estimated recurrence interval of 17 years. At Vienna, bank-full storage conditions occur when the stream discharge exceeds 6200 cfs, a condition which probably occurs on an average of once in 13 years.

At the time of the field investigation (summer of 1965), surface-water supplies on the main streams seemed adequate to meet irrigation demands. Since very little surface water is withdrawn for any consumptive use other than irrigation (see Figure 25) the resource is not generally overtaxed even though conflicts resulting from use by irrigators do take place on smaller streams. Where such problems occur, storage of surface waters collectively or by individual irrigators can help to alleviate water shortages during times of heavy demand.

The quantitative assessment of the individual elements of the hydrologic budget for the basin was limited to an estimate of total precipitation over the basin during the water year ending in 1965 and of total stream discharge during the selected period. The difference between precipitation and runoff was attributed mainly to evapotranspiration. Included with evapotranspiration are all the other undetermined parameters of the budget equation: net underflow, and net changes in ground-water, surface-water and soil-moisture storage. Since significant bodies of open water are not present in the basin, the change in surface-water storage can be justifiably neglected from evaluation. The other three parameters of underflow and the changes in ground-water and soil-moisture storage were not estimated due to the lack of pertinent data. Their probable effects on the budget were assessed to be minor.

Total precipitation for the budget year was estimated to be 30.81 inches over the area of the basin. Of this total, runoff was calculated to be 15.10 inches and "evapotranspiration" 15.71 inches. The precipitation was 6.85 inches below the calculated normal of 37.66 inches at Delhi. The "evapotranspiration" was

7.66 inches below the potential evapotranspiration as calculated by the Thornthwaite method.

Further evaluation of the hydrologic-budget elements will depend largely on the type and amount of data available. The present coverage of automatic stream-gauging stations (see Map 2705-7) is adequate for this purpose and no improvement in instrumentation is considered necessary. Similarly, the adequacy of the rainfall network, although not ideal, is considered satisfactory for the estimation of rainfall over the basin. During the survey, observation wells were installed at five sites (see Map 2705-7) to record ground-water levels from which changes in ground-water storage could be calculated. The network can be considered adequate for calculating changes in ground-water storage in unconfined aquifers, but it is not extensive enough to provide sufficient data for evaluations of changes in confined aquifers. Many new observation wells would be needed to determine underflow; the costs of obtaining such wells were not considered justified for the present survey.

As is often the case, water supplies of adequate quantity may be rejected due to quality requirements that render the water unacceptable for specific purposes. In this report, the investigation of the suitability of supplies in terms of the chemical quality of water for domestic and irrigation uses was considered as a part of the resource evaluation.

The majority of overburden and bedrock ground waters, and all stream waters are of the calcium-magnesium bicarbonate type. In terms of six characteristics of water — chloride, iron, nitrate, sulphate, total dissolved solids and hardness — water from most wells and streams in the basin is of good quality and suitable for domestic, stock and irrigation uses. The bacteriological quality should be determined on an individual basis before a source of supply is utilized for domestic purposes.

In the southern third of the basin the suitability of the waters from the bedrock formations for irrigation is doubtful. Sodium and salinity can be high and variable and waters should be examined closely before being used for irrigation.

The use of ground and surface waters in the basin in 1965 was estimated to be 984 million gallons, an amount equivalent to a continuous rate of streamflow of approximately 5 cfs. This rate is much less than the median flow in Big Otter Creek at Vienna of 190 cfs. Although the average use is far less than the median flow, the peak demands placed on surface waters for irrigation necessitate the construction and management of local storage reservoirs. Such reservoirs would be particularly useful in the headwaters if ground water does not provide an adequate alternative supply and elsewhere where the streams have intermittent or low summer flows. Sound management principles require, in part, that reservoirs be provided and utilized to maintain sufficient streamflow to meet the demands upon surface waters for both withdrawal and onstream uses.

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APPENDIX A

Records of Selected Water Wells in the Big Otter Creek Drainage Basin

Only those wells of which direct mention is made in the report appear in this appendix. Logs for all other wells, shown on Map 2705-1, are on file with the Division of Water Resources, OWRC.

Abbreviations Used

Bk	— black	Hd	— hard	S.G.	— South Gore
Bl	— blue	Hp	— hardpan	Sh	— shale
Bld	— boulders	Lay	— layer	Shy	— shaly
Bn	— brown	Ls	— limestone	Slt	— silt
Cem	— cemented	Lse	— loose	Sm	— small
Cl	— clay	Med	— medium	Str	— streak(s)
Cly	— clayey	N	— north	Sts	— stones
Co	— county	NG	— North Gore	Sty	— stony
Con	— concession	Pbl	— pebble	Sity	— Silty
Cse	— coarse	Qsd	— quicksand	T.R.N.	— Talbot Road North
Dk	— dark	Rk	— rock	T.R.S.	— Talbot Road South
Dty	— dirty	S	— south, sulfur	Ts	— topsoil
F	— fine	Sd	— sand	Twp	— Township
Gr	— gravel	Sdy	— sandy	Wh	— white
Gry	— gravelly	Sf	— soft	Yl	— yellow
Gy	— grey				

Appendix A — Records of Selected Water Wells in the Big Otter Creek Drainage Basin

(locations of numbered wells are shown on Map 2705-1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Log and Remarks (Depths to which formations extend below the surface are given in feet)
	OXFORD CO. Twp. of N. Norwich						
19	Con I Lot 22	J. Zelich	Sept 7/62	5	35	10	Cl Sts 21; Dty Gr 32; Cse Sd 35. Water at 32 to 35.
20	" I " 23	L. Schaafsma	April 14/55	3	274	35	red Cl 28; Hp 59; Gr 80; Cl 98; Sdy Cl 109; Sd 176; Hp 254; Ls 274. Water at 274.
54	" III " 8	E. Casler	Dec 6/63	5	75	20	Sd 30; Bl Cl 65; Cl Blds 72; Bn Ls 75; Water at 74.
56	" III " 10	D. Carroll	April 6/62	5	132	33	Ts 1; Sd 28; Sdy Cl 34; Sd 40; Cl Sd 55; Gr Cl 97; Bl Cl 130; Ls 132. Water at 132.
60	" III " 17	K. Hamulecki	June 23/61	5	107	15	Cl 20; Sd 40; Sts Cl 107. Water at 107.
69	" IV " 12	A. Hanson	Dec 12/63	5	114	50	Bn Cl 15; Bl Cl 60; Sd 65; Hp Sts 113; F Gr 114. Water at 114.
71	" IV " 15	W. Mitchell	Sept 20/59	5½	160	45	Bn Cl 15; Bl Cl 60; Qsd 100; Hp 150; Sh 154; Ls 160. Water at 158.
72	" IV " 16	K. Dyment	Nov 11/58	5½	152	30	Bl Cl 50; Sd 120; Hp Sts 150; Ls 152. Water at 151.
75	" IV " 21	J. Redling	July 31/65	5	66	14	Cl loam 1; Yl Cl 14; Gy Cl 26; Wh Sd 30; Sf Cl 61; Gr Sd 66. Water at 26 to 30 and 61 to 66.
77	" IV " 23	W. Carrow	July 23/58	5½	102	15	Bn Cl 40; Sd 50; Bl Cl Sts 100; Gr 102. Water at 100.
79	" IV " 25	W. Hastings	Oct 23/53	5	67	20	Cl 14; Qsd 36; Bl Cl 52; Gr 67. Water at 52.

80	" IV " 27	I. McIntyre	Dec 30/60	5	56	12	Ts 3; red Cl 10; Bl Cl 30; Slt 55; Gr 156. Water at 55.
82	" V " 1	E. Fewster	Jan 27/59	6½	104	40	Sty Sd 40; Cl 60; Slty Cl 102; Gr 104. Water at 102.
83	" V " 3	J. Sutton	Feb 24/59	6½	72	12	Sd 8; Cl 40; Sd Cl 72. Water at 72.
85	" V " 5	S. Mott F. Charlton	Feb. 7/62	5	49	28	Ts 1; Gy Sd 20; Cem Sd Gr 47; Gr 49. Water at 47.
86	" V " 6	D. Moore	Sept 14/60	5	70	45	Cl Sts 8; Gr 14; Gy Cl 34; Dty Gr 50; Gr 70. Water at 50.
90	Gore " 67	E. Ryckman	Feb 14/59	7	104	40	Sd 10; Cl 40; Sd Cl mixed 104. Water at 104.
92	Con V Lot 14	J. Hinks	Aug 22/54	4	146	15	Sdy loam 4; Bl Cl 50; putty Sd 70; Gy Cl 144; Ls 146. Water at 146.
94	" V " 19	D. Sackrider	Mar 25/63	5	160	50	Bn Cl 20; Bl Cl 45; Bl Cl Sd Lays 60; Bl Cl 150; Wh Hp 152; Ls 160. Water at 160.
95	" V " 20	E. Pritchard	Feb 28/61	5	155	9	Ts 3; red Cl 8; Bl Cl 25; F Sd 40; Bl Cl 73; Gr 75; Bl Cl Sts 151; Br Lms 155. Water at 73 to 75 and at 154.
96	" V " 21	C. Neyens	Apr 5/60	5	92	7	Cl 6; Lse Gr 20; Gr Sd Bld 81; Sd 92. Water at 81.
98	" V " 22	Newark United Church	May 20/60	4½	88	15	Bl Cl 87; Gr 88. Water at 87.
99	" V " 23	R. Sims	Nov 16/60	5	127	24	Bl Cl 100; Hp Sts 122; Bn Ls 127. Water at 126.
100	" V " 26	M. Chamak	May 25/64	5	114	28	Yl Sd 8; Cl St 61; Dty Gr 75; Cl Sty 102; Hp 110; Gy Ls 114. Water at 114.
101	" VI " 3	E. Vandenberghe	July 14/62	2	46	17	Ts 1; Sd 24; Sd St 46. Water at 17.
111	" VI " 22	M. Shetler	Mar 19/64	5	119	35	Bl Cl 55; Gr 63; Cl 83; Bl Cl 118; Rk 119. Water at 119.
114	Village of Norwich	Norwich P.U.C.	Jun 5/51	10	191	40½	Sdy loam 3; Cl Gr 6; F Sd 11; Cl Gr 47; Cem Gr 48; Cse Gr 80; Cl Gr 91; Gr Sd 96; Cl Gr 99; Ls 191. Water at 132 to 135.

Appendix A — Records of Selected Water Wells in the Big Otter Creek Drainage Basin

(locations of numbered wells are shown on Map 2705-1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Log and Remarks (Depths to which formations extend below the surface are given in feet)
	Twp. of S. Norwich						
136	Con VII Lot 9	J. Mayer	Aug 16/59	5	85	21	Dug 5; Cl Yl Sd 42; Cl 82; Gr 85. Water at 82.
148	" VIII " 2	R. Vuylsteke	Apr 15/60	2	25	6	Fill 3; Yl Sd 12; Cl 15; Br Sd 18; Cse Sd 25. Water at 18.
158	" VIII " 24	A. Bartlett	July 14/55	4	62	34	Sf Cl 40; Hd Cl 60; F Gr 62; Water at 60.
175	" X " 8	H. Arthur	Apr 16/58	5½	153	60	Ts 2; Yl Sd 16; Cl 56; Sd Cl 104; Cl 110; Soupy Sd 144; Cl 147; Gr 150; Wh Ls 153. Water at 153.
177	" X " 9	A. Juhasz	Aug 31/62	5	86	32	Dug 16; Yl Sd 27; Wh putty Sd 50; Gy Cl Sts 62; putty Sd 78; F Sd 86. Water at 78.
184	" X " 21	R. Mason	Feb 20/60	5	95	45	Cl Sts 72; Gy Cl Sts 91; Gr 95. Water at 91.
199	" XI " 18	R. Hurley	July 10/59	3	20	10	Ts 1; Yl Sd 4; Gy Sd 10; F Gr 20. Water at 10.
211	" XII " 19	P. Osaer	Apr 29/61	1½	25	15	Ts 1; Yl Sd 5; Wh Sd 15; Bn Qsd 25. Water at 15.
213	" XII " 20	J. Stover	Nov 18/59	2	30	5	Yl Sd 5; Sharp Sd 30. Water at 6.
222	" XII " 27	J. Hurley	Apr 1/59	1½	16	7	Ts 1; Yl Sd 5; Wh Sd 16. Water at 7.
853	" IX " 26	O.W.R.C.	Jan 19/66	7	121	51	Bn Sdy Soil 1; F Bn Sd 10; F Sd Slt 38; Gy Bn Cl Slt 52; Cse Gr 53; Gy Bn Cl till 60; F Gr Cse Sd 61; F Hd Sd 76; Gy Slt Cl Lays 88; Gy Cl till some Sts 112; Gy Wh Ls 121. Water at 112.
	Twp. of Dereham						
227	Con IV Lot 1	O. Chambers	Jan 3/64	5	72	16	Bk loam 3; red Cl 20; red Sd 60; Sd Gr 72. Water at 60.

228	"	IV	"	9	J. Van De Munt	July 19/56	6	65	42	Ts 3; Cl Sts 60; Gr 65. Water at 60.
229	"	V	"	3	J. Morris	Aug 24/59	5	53	0	Yl Cl 10; Gy Cl 45; Sd Gr 53. Water at 53.
230	"	V	"	7	V. Franklin	Apr 18/62	5	158	50	Cl loam 3; Cl Blds 20; Wh Sd Cl 28; putty Sd Cl 30; Gy Cl 33; Dty Gr 125; Cl 158; Gr and Rk 158+. Water at 158.
231	"	V	"	7	C. Scott	Oct 21/55	6	94	6	Yl Cl Pbl 14; Sft Gy Cl 50; F Sd 65; putty Sd 85; Cl Sf 90; Dty Gr 94. Water at 94.
232	"	V	"	8	C. Prouse	Feb 18/64	5	70	30	Ts 2; Cl Sts 65; F Sd 70. Water at 65.
237	"	VI	"	4	C. Mansfield	May 13/60	5	105	24	Ts 8; Cl Sts 16; Cl 40; Dty Gr 104; Gr 105. Water at 104.
238	"	VI	"	8	B. Preston	Oct 11/49	4	182	14	Bn Sd 3; Bl Cl 138; Gr 143; Bl Cl Sts 180; Ls 182. Water at 182.
259	"	VII	"	14	R. McLaughlin	July 21/63	5	141	30	Previously drilled 60; Gy Cl Sts 110; Dty Gr Str Cl 136; Gr 141. Water at 136.
269	"	VIII	"	10	C. Fishback	Jun 15/55	5½	108	88	Cl 60; Sd 105; Hp 108; Gr 108+. Water at 108.
277	"	VIII	"	22	W. Forman	Dec 22/55	5½	92	30	Bl Cl 60; Sd 90; Hp 92; Gr 92+. Water at 92.
279	"	IX	"	1	H. Huges	Sept 3/63	5	168	90	Cl 80; Gr 100; Cl 120; Gr 140; Cl 161; Rk 168. Water at 168.
280	"	IX	"	3	H. Livingston	May 6/61	5	112	82	Yl Cl 14; Sd 16; Gy Cl 28; Sd 58; Gy Cl Sts 103; Dty Gr 105; Sd 112. Water at 105.
309	"	X	"	1	A. Lambert	Mar 30/64	5	141	60	red Cl 20; Bl Cl 100; Gr 110; Bl Cl 144; Gy Ls 145. Water at 145.
350	"	X	"	11	A. Horvath	Aug 18/62	5	91	28	Yl Cl 8; Gy Cl Sts 25; Dty Gr 58; Hd Cl Sts 72; Yl Sd 80; Cse Sd 91. Water at 80.
352	"	X	"	12	J. Pettman	May 12/59	5	73	25	Sd 15; Gr 25; Hp Cl 40; Bld Cse Gr 60; F Gr Cl Lay 65; Cse Sd 73. Water at 65.
353	"	X	"	12	Tillsonburg P.U.C.	Jun 12/61	2	164	16½	Bk loam 2; Yl Sd 18; Yl Cl 20; Gy Qsd 28; Med Sd 30; Cl Hp 68; Cse Sd 82; Cse Sd F Gr 85; F Gr 93; Cl 118; F Gr 126; Cl Sd 136; Bl Cl 161; F Sd Gr 163; Ls 164. Water 68 to 93; 118 to 126 and at 161.

Appendix A — Records of Selected Water Wells in the Big Otter Creek Drainage Basin

(locations of numbered wells are shown on Map 2705-1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Log and Remarks (Depths to which formations extend below the surface are given in feet)
354	" X " 12	Tillsonburg P.U.C.	Oct 31/61	2	162		Ts 1; Dty Sd 7; Sd Cl 14; Slt Cl Str 22; Cl Gr 70; Sd 71; Sft Cl 79; Slt Sd 83; Cse Sd F Gr 86; Cl 162; Rk 162+.
358	" X " 15	R. Crawford	Mar 17/61	5	100	40	Cl loam 18; Wh Sd 20; Sft Gy Cl 55; Cl Sts 92; F Gr 100. Water at 92.
359	" X " 15	H. Brown	Nov 16/62	5½	99	24	Bn Cl 25; Hd Sd 50; Cl Sts 80; putty Sd 90; Hp 90; Gr 199. Water at 98.
397	" XI " 10	Tillsonburg P.U.C.	Oct 26/61	5	149		Ts 1; Dty Sd Cl 45; Bn Cl 12; Bl Cl Gr odd Bld 49; F Gr 52; Cl str 52½; Slt Sd 55; Cl 57; Sd 58; Cl 64; Slt F Sd 72; tight Slt Sd Cl Str 97; Cl Blds 105; Cl 149; Rk 149+.
403	" XI " 14	R. Oldridge	Jun 11/48	4	90	Flows	Cl 84; Gr 90.
405	" XI " 14	Z. Smith	Apr 23/53	4	123	Flows	Bn Cl 15; Bl Cl very sty 55; Yl Sd 118; Hp 122; Gr 123. Water at 122.
406	" XI " 14	M. Hewer	Jun 10/61	5	92	0	Dug 40; Gy Cl St 86; F Sd 89; Cse Sd 92. Water at 89.
408	" XI " 15	W. Doddsley	Mar 31/53	4	98	Flows	Bk Cl 3; Yl Sd 13; Cl Blds 97; Gr 98. Water at 97.
427	" XII " 7	J. Sanders	Apr 27/61	1½	40	25	Sdy Cl 4; Bn Sd 28; F Gy Sd 40. Water at 28.
447	" XII " 10	Tillsonburg P.U.C.	Jun 20/60	5	170	20	Yl Cl Pbls 19; Yl Sd 30; Dty Sd 77; Cl Sts 85; Cl 169; Ls 170. Water at 30 to 77.
465	Town of Tillsonburg	Borden Co. Ltd.	Nov 2/48	6	105	65	Ts Sd 3; Cl 55; muddy Sd 75; Cl 97; Rk 102; flakey Ls 103; Ls 105. Water at 102.
	BRANT CO.						
	Twp. of Burford						
126	Con XIII Lot 17	M. McCready	Apr 11/39	6	142	70	Cl 87; F Sd 130; Cem Sd Rk 142. Water at 130.

127	" XIII " 18	G. Atlee	Oct 28/60	1½	33½	6	Bk muck 3; F Sd 7; Slty Cl 10; F Sd 17; Sd Sm Sts 33½. Water at 26.
128	" XIII " 21	E. Groulx	Nov 26/60	4	87	16	Loam 4; Bn Cl 21; Bl Cl 30; F Sd 51; Sft Cl 72; Hd Cl 86; Gy Ls 87. Water at 87.
129	" XIV " 24	H. Jansen	Aug 10/62	5	81	17	red Sd 18; Sft Bl Cl 80; Gr 81. Water at 81.
	NORFOLK CO.						
	Twp. of Windham						
130	Con I Lot 19	J. Johnson	Dec 23/63	4	158	60	Yl Sd 6; Cl St 60; Qsd 120; Cl Blds 153; Gy Rk 158. Water at 158.
	Twp. of Middleton						
	T. R. N.						
708	I - 3	J. Strobel	Apr 13/56	4	30	9	red Sd 6; Bn Sd 10; Sd 37. Water at 10.
709	I - 5	L. Stillwell	Dec 5/61	5	33	15	Sd 24; F Sd 33. Water at 24.
712	I - 6	G. Frankea	May 15/61	2	37	3	Sdy Cl 3; putty Sd 18; Cl 21; Cse Sd 37. Water at 21.
720	I - 16	Backus Lumber Co.	May 14/59	1½	27	14	Sdy Ts 14; F Sd 19; Cse Sd 27. Water at 14.
722	I - 19	J. Fody	Apr 13/62	5	75	2	Cl Sts 45; Sd Cl 70; Sd 75. Water at 70.
725	I - 20	H. Purdy	Aug 3/54	3	178	40	red Sd 15; putty Sd 30; Cl 170; Rk 178. Water at 178.
734	I - 21	Courtland Packers	Aug 25/56	7	182	39	Yl Sd 12; putty Sd 20; Gy Cl 58; putty Sd 85; Gy Cl Pbls 155; Cl Gr 170; Ls 182. Water at 182.
796	II - 16	W. Rooke	Oct 1/58	4	63	12	Dug 32; Gy Cl 52; Dty Sd 58; Sd 63. Water at 60.
800	II - 17	M. Harvey	Aug 12/59	5	73	13	Yl Sd 8; Gy Cl 61; Sd 73. Water at 61.
803	II - 18	J. Penneman	July 2/58	5½	198		Sdy loam 3; Cl 54; mixed putty Cl 110; Cl Sts 173; Gy Ls 198. Dry Hole.
804	II - 18	J. Penneman	July 2/58	4	70	9	Cl 54; F Sd 70. Water at 54.

Appendix A — Records of Selected Water Wells in the Big Otter Creek Drainage Basin

(locations of numbered wells are shown on Map 2705-1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Log and Remarks (Depths to which formations extend below the surface are given in feet)
805	II - 18	Eckford & Loughdon Constr	July 14/58	2	73	8	Ts 6; Hd Gy Cl 63; F Wh Sd 73. Water at 63.
818	III - 7	B. Stonkus	Oct 23/54	4	247	196	Gy Cl 80; Sd 96; putty Sd 180; Sft Cl 246; Shelly Rk 247. Water at 246.
828	III - 14	J. Seres	July 26/55	10	168	61	Ts 5; Sd 55; Bl Cl 65; Sd Gr 75; Bl Cl 162; Dk Gy Ls 168. Water at 65 to 75, and 162 to 166.
829	III - 14	J. Seres	Mar 30/63	5	46	18	Yl Sd 22; Wl Sd 35; Sd 46. Water at 35.
832	III - 15	A. Radocz	July 11/60	3	65	7	Ts 3; Yl Sd 32; Sd Cl Strs 47; Sd 65. Water at 47.
834	III - 15	Livingston Wood Mfg. Co.	Oct 10/61	8	67	17	Yl Sd 8; putty Sd Cl Strs 44; Sd 67. Water at 44.
835	III - 15	Tillsonburg P.U.C.	Oct 12/61	2	91		Ts 3; Sd 5; Sft Bl Cl 10; Sd 50; F Sd 70; Sd 79; Bl Cl 91.
839	III - 17	J. Narh	Nov 1/53	1½	52	14	red Sd 40; Wh Cl 42; F Sd 52. Water at 42.
841	IV - 2	J. Mikenas	Jun 12/61	1½	37	17	Dug 17; Gy Qsd 37. Water at 17.
847	IV - 10	C. Garnett	Nov 5/60	1½	27	18	Ts 1; Yl Sd 4; Wh Sd 14; Bn Hp 18; Bn Sd 27. Water at 18.
851	IV - 10	A. Vodden	Jun 22/64	1½	24	15	Ts 1; Yl Sd 5; Wh Sd 15; Bn Sd 24. Water at 15.
874	T. R. S. I - 14	N. Muller	July 9/59	2	23	5	Dk Sd 4; Sd 23. Water at 5.

883	I - 21	St. Ladislaus Subdivision	Nov 23/62	8	162	35	Yl loam 6; Gy Cl Pbl 85; Gy putty Sd 101; Cl Sts 162; Sh 162+. Water at 162.
912	I - 24	R. Chapman	Jun 2/64	1½	38	12	Dug 6; Gy Sd 12; Hd Bn Sd 19; Sd 38. Water at 19.
914	I - 25	E. Braun	Mar 20/62	4	50	20	F Sd 30; Sd 50. Water at 30.
918	I - 26	M. Loebel	Nov 29/62	2	50	22	Ts 18; Cl 32; Sd 38; Gy Sd. 50. Water at 40.
925	III - 27	E. Martin	Jan 14/61	1½	20	9	Dug 5; Yl Sd 9; Bn Qsd 20. Water at 9.
	ELGIN CO.						
	Twp. of Malahide						
	T. R. N.						
506	99	B. Balaz	Nov 7/52	5	139	76	Hd Cl 120; Cl Sts 135; Bld 136; Gr Sd 139. Water at 136.
507	100	W. Lang	Aug 20/63	5	178	60	Dug 5; Yl Sd 12; Sft Gy Cl 50; putty Sd 65; Gy Cl Sts 172; Dty Sd Strs Cl 178. Water at 172.
509	105	A. Benner	Sept 28/59	5	140	90	Ts 2; red Cl 30; Bl Cl 80; F Sd 90; Bl Cl 135; Cse Sd 140. Water at 135.
510	106	R. Abell	Jan 7/63	5	253	60	Yl Sd 3; Yl Cl 20; Wh Sd 23; Gy Cl Sts 87; red Wh Sd 92; Hd Gy Cl 140; red Wh Sd 149; Gy Cl 210; putty Sd 230; Gy Cl 251; Shelly Rks 253. Water at 253.
511	106	R. Abell	Mar 27/63	5	117	92	Yl Cl 20; Gy Cl Sts 32; putty Sd 35; Gy Cl Sts 80; Sd 117. Water at 105.
	T. R. S.						
516	100	L. Oliver	Jun 27/63	5	252	50	Yl Cl 16; Gy Cl 165; Gy Cl Sts 200; Gy Cl Strs putty Sd 245; Gy Cl St 251; Gr 252. Water at 251.
517	103	M. Carter	Apr 16/64	5	74	40	Blk loam 2; Yl Cl 14; Sft Gy Cl 66; Sd 74. Water at 66.

Appendix A — Records of Selected Water Wells in the Big Otter Creek Drainage Basin

(locations of numbered wells are shown on Map 2705-1)

Well No.	Location	Recorded Owner	Completion Date	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Log and Remarks (Depths to which formations extend below the surface are given in feet)
	Twp. of Bayham						
522	Con III Lot 16	A. Goethals	Sept 16/59	1	21	7	Bn Sd 3; Yl Sd 9; Sd 21. Water at 21.
524	" IV " 4	H. Millard	Apr 26/60	5	184	30	Yl Sd 10; Gy Cl 100; Gy Cl Sts 165; Gr 174; Cl Sts 181; Ls 184. Water at 165 to 174 and at 184.
530	" IV " 18	F. Voros	Aug 23/62	5	283	160	Yl Sd 15; Gy Sd 33; Gy Cl 203; Gy Cl Sts 281; Blk Sh 283. Water at 283.
537	" V " 11	J. Wolf	Mar 14/61	1½	24	15	Ts 1; Yl Sd 4; Bn Cl 9; Wh Sd 15; Bn Sd 24. Water at 15.
539	" V " 18	T. Herman	May 26/59	1½	17	7	Bn Sd 2; Yl Sd 11; Very F Sd 17. Water at 11.
542	" VIII " 1	J. Daradics	Nov 11/61	5	88	1	Loam 4; Gy Cl 21; Sdy Cl 55; Bl Cl 70; Sd 88. Water at 71.
549	" VIII " 10	C. Jackson	Mar 25/62	5	89	66	Yl Sd 76; F Sd 89. Water at 76 to 89.
559	" VIII " 22	Hicks & Lawrence	Nov 19/55	6	100	73	Dug 5; Hd Yl Cl 18; Yl Sd 52; putty Sd 90; F Sd 100. Water at 100.
585	" IX " 6	S. Balaz	Sept 10/51	4	196	2	Yl Sd 20; Cl 58; soupy Cl 185; shell Rk 186; broken Rk 196. Water at 188 and at 196.
589	" IX " 9	J. Dewaele	July 5/57	1½	25	15	Ts 1; Yl Sd 4; Bn Sty Cl 11; Bn Sd 15; Bn Qsd 25; Bn Cl 25+. Water at 15 to 25.
611	" X " 10	I. Cowan	Oct 23/64	5	186	30	Blk loam 2; Yl Cl 10; Sft Gy Cl 65; Gy Cl Sts 148; Sft Gy Cl 186; Rk 186+.
621	" X " 15	N. Byerly	Mar 7/64	5	55	46	Cl Sts 50; F Sd 55. Water at 50.

643	S. G.	19	N. Szalatvan	July 19/51	5	265	40	Sd 18; Bl Cl 68; Cl Sts 128; Bl Cl 208; Cl Sts 264; Gr 265. Water at 265.
646	T. R. N.	116	G. Balaises	July 3/59	5	275	—	Cl Sts 40; Yl Sd 86; putty Sd 120; Sft Gy Cl 180; Sft Cl Sd 220; Cl 274; shelly Rk 275.
647	"	120	V. Tisdale	Apr 22/51	4	287	100	Sd 60; Cl 130; Qsd 270; Bl Cl 281; Ls 287. Water at 287.
667	"	127	R. De Clereq	Feb 17/59	5	233	100	Bn Sd 30; Bl Cl 40; Gy Sd 52; Bl Cl 110; putty Sd 145; Cl 151; putty Sd 176; Bl Cl 200; Bld 205; Hp Cl 228; F Gr 233. Water at 228.
670	"	129	J. Kennedy	Apr 8/61	1½	35	22	Ts 1; Yl Sd 4; Bn Hp 12; Wh Sd Strs Hp 22; Gy Qsd 35. Water at 22.
671	T. R. S.	110	C. Milmine	Jun 2/62	5	247	90	Sd 36; Bl Cl 43; muddy Sd 77; Bl Cl 194; muddy Sd 239; Gy Sh 242; Blk Slate 247. Water at 242.
674	"	123	J. Murphy	Feb 1/60	1½	40	23	Dug 25; Cse Bn Qsd 40. Water at 23.
697	"	126	M. Volkaert	July 7/64	1½	40	25	Gy Sd 23; Hp 26; Gy Sd 40. Water at 26.
698	"	128	M. Pokorny	Oct 29/60	1½	41	12	Yl Sd 10; Cl 20; Sd 41. Water at 20.

APPENDIX B

Chemical Analyses of Waters in the Big Otter Creek Drainage Basin

Appendix B — Chemical Analyses of Waters in the Big Otter Creek Drainage Basin

(locations of water sampling points are shown on Map 2705-9)

Source	Sampling Point No.	Date of Collection	Ionic Concentrations in parts per million									pH	Total Hardness as $CaCO_3$ (ppm)	Specific Conductance (mmhos at 25°C)	Total Dissolved Solids (ppm)
			Sodium as Na	Potassium as K	Calcium as Ca	Magnesium as Mg	Bicarbonate as $CaCO_3$	Sulphate as SO_4	Chloride as Cl	Nitrate as N	Total Iron as Fe				
Well	19	July 29/65	8	1.6	18	49	355	44	5	0.00	1.20	7.7	250	410	312
"	20	June 30/65	13.5	1.5	44	25	223	26	2	0.00	0.30	7.9	214	380	290
"	54	"	24.5	1.6	38	21	212	10	3	0.00	0.40	8.1	184	370	332
"	60	July 29/65	28.0	1.3	30	20	179	39	4	0.15	4.00	8.1	156	355	270
"	83	"	48.0	1.8	50	19	170	83	29	0.00	0.53	7.7	204	480	366
"	96	"	16.5	1.8	18	18	176	10	3	0.00	5.50	8.0	120	290	256
"	111	June 30/65	61.5	0.95	18	11	109	89	5	trace	1.5	8.5	86	380	272
"	130	"	13.5	1.6	52	27	245	13	3	0.00	0.95	7.9	242	420	348
"	136	July 20/65	4.6	1.2	80	19	252	34	6	0.00	5.30	7.6	820	490	328
"	148	"	2.6	1.75	40	25	158	44	5	0.40	0.20	8.1	206	345	328
"	158	"	30.5	47.50	33	100	371	127	89	1.30	0.13	7.6	504	980	814
"	175	June 30/65	36.0	0.9	14	4	120	16	4	0.00	0.14	8.3	54	200	246
"	177	July 29/65	5.5	1.3	42	34	248	15	3	0.00	3.00	8.0	244	400	294
"	184	"	50.0	1.4	26	13	236	0	4	trace	1.40	8.2	122	370	278
"	211	"	9.5	1.75	46	41	164	95	18	0.20	0.28	7.8	284	510	426
"	222	"	7.5	120.0	68	23	313	50	15	10.0	0.15	7.8	266	800	600
"	227	"	7.5	1.45	30	35	221	13	4	0.00	0.51	8.0	222	360	310
"	228	"	6.0	1.7	28	49	251	34	5	0.00	0.70	7.7	274	449	340
"	237	"	45.5	1.75	21	15	188	39	5	0.15	0.30	8.2	114	355	256
"	238	June 30/65	42.5	1.5	26	15	172	34	6	0.00	0.20	8.1	130	340	290
"	259	July 29/65	8	1.85	46	80	312	89	23	5.00	0.20	7.7	448	730	592
"	269	"	68	1.15	28	12	79	166	5	0.00	0.27	8.2	122	449	418
"	277	"	13.5	1.75	55	57	206	147	47	0.15	0.70	7.8	374	645	558

"	279	"	36.5	1.3	21	14	158	24	3	0.0	0.18	8.3	110	290	492
"	280	"	33.0	1.2	18	15	169	13	3	0.0	1.40	8.2	106	275	198
"	358	"	63	2.2	11	12	165	35	7	0.25	0.20	8.4	76	350	274
"	522	July 15/65	2.3	1.6	56	8	96	72	8	0.54	0.22	8.1	172	290	242
"	524	June 30/65	6	1.5	111	18	289	71	13	2.0	0.20	7.7	354	600	516
"	530	"	280	3.2	30	32	177	30	440	0.0	36	8.3	210	1490	1064
"	537	July 15/65	11.6	3.45	87	12	287	55	16	3.02	0.02	7.7	270	500	382
"	539	"	11.6	6.25	112	12	188	101	20	20.0	0.10	7.8	332	620	532
"	542	"	85	1.75	20	8	257	0	17	0.0	3.9	8.2	82	410	326
"	549	"	3.6	1.55	89	14	238	41	4	trace	0.52	7.7	280	450	336
"	559	"	8.8	2.7	98	21	151	82	19	0.0	3.61	7.6	330	550	478
"	585	June 30/65	105	1.8	35	24	259	174	30	0.0	1.7	8.6	186	660	566
"	621	July 15/65	5.4	1.1	90	22	274	40	5	0.0	1.3	7.6	314	495	362
"	647	June 30/65	195	5.3	52	35	280	83	202	0.0	3.9	8.0	274	1150	784
"	670	July 15/65	2.1	1.55	86	12	232	71	10	2.40	0.70	7.8	262	430	362
"	671	June 30/65	125	2.3	16	8	234	9	56	0.0	0.71	8.1	82	510	434
"	709	July 15/65	3.2	0.9	54	9	171	25	7	0.0	2.4	7.8	174	280	264
"	720	"	2.6	1	67	11	163	46	10	0.0	1.2	7.8	214	350	288
"	734	June 30/65	28.5	1.7	61	22	266	20	12	0.0	0.61	8.1	242	460	362
"	796	July 29/65	35	1.3	10	6	124	0	3	0.00	0.30	8.0	50	210	182
"	818	June 30/65	67.5	1.5	6	8	140	4	25	0.00	0.10	8.4	50	300	258
"	841	July 15/65	3.7	0.95	75	12	160	58	16	0.0	0.11	7.9	240	400	346
"	847	"	18.1	24	98	17	217	93	26	1.87	0.31	8.0	316	610	558
"	925	"	24	1.9	82	12	232	43	26	0.0	2.9	7.5	254	500	394
Lake Erie	1	Oct 14/65	11.3	1.2	40	7	100	22	26	0.0	1.6	8.3	128	295	280
Big Otter Cr.	2	"	8.8	1.6	82	14	200	56	16	0.1	0.52	8.2	264	475	366
Big Otter Cr.	3	Oct 21/65	8.6	0.2	78	18	202	56	15	0.40	0.35	8.0	268	450	360
Little Otter Cr.	4	"	4.6	1.2	77	16	202	49	9	trace	0.28	8.2	256	420	320
Stony Cr.	5	"	12.0	2.3	86	18	222	55	24	0.40	0.15	8.3	286	500	364
Spittler Cr.	6	"	5.1	2.3	90	15	220	48	12	0.50	3.30	7.9	286	480	356
Branch Cr.	7	"	5.9	3.4	85	18	214	55	12	0.60	0.11	8.1	282	470	328
Big Otter Cr.	8	"	6.2	1.6	74	17	190	52	10	0.50	0.11	7.8	252	420	280
Rain Water	Tillsonburg	"	0.2	0.5	2	2	10	10	3		0.14	7.1	14	22	16